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TER QUALITY ANALYSIS UNIT-PURIFICATION (WQAU-P)
_TIPARAMETER SENSOR

lie S. Rubin
ter-Miller, Inc.
Second Avenue
tham, MA 02254

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The multiparameter sensor of the Water Quality Analysis Unit-Purification (WQAU-P) developed under contract DAAK70-85-C-0022 was replaced by a specially designed Foster-Miller, Inc., multiparameter sensor that is capable of measuring temperature, pH, TDS and turbidity. The original WQAU-P circuitry for these parameters as well as the microprocessor software was revised/redesigned. The high level of instrument automation incorporated into the WQAU-P design allows trained users to complete a calibration and measurement sequence in less than 5 minutes. The end product is capable of providing the quantitative measurements needed to establish the effectiveness of a Reverse Osmosis Water Purification Unit (ROWPU) and/or determine the treatability of a raw water source. The WQAU-P occupies 2.0 cubic feet and weighs 46 pounds.

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SUMMARY

The U.S. Army, as well as other military branches, uses a Water Quality Analysis Set/Purification to determine the treatability of a raw water source and/or monitor the performance of a water purification system. This water quality analysis set weighs in excess of 55 lb, occupies approximately 4.4 ft and uses wet chemistry in the analysis process. Personnel must be well trained to perform these analytical procedures and normally require 45 to 60 min to perform a complete measurement routine which includes temperature, pH, TDS, turbidity and residual chlorine. With extensive user involvement, this wet chemistry approach is subject to human error. Replacement of the active chemicals also presents a materials logistics problem.

In an effort to reduce the weight, size and operational complexity of the WQAS/P, Foster-Miller, Inc. initially developed a Phase I prototype Water Quality Monitor (WQM) that demonstrated instrument feasibility. The successful Phase I WQM was then redesigned into a Phase II militarized unit. This Phase II unit, the Water Quality Analysis Unit - Purification (WQAU-P), like the Phase I WQM combined state-of-the-art electronic monitoring instrumentation with a powerful microprocessor. Calibration and measurement operations were greatly simplified. Personnel experienced in the WQAU-P's operation could perform a complete calibration and measurement sequence in less than 5 min. The potential for human error was greatly reduced by eliminating wet chemistry analyses and incorporating electronic calibration algorithms.

The Phase II WQAU-P, while meeting many of the contract goals, required improvements in two specific areas:

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- An improved multiparameter sensor to replace the commercially available Horiba Model U-7 sensor that measured temperature, pH, TDS and turbidity

- An improved case design to better withstand rough handling and harsh environments.

The follow-on Phase III WQAU-P contract (awarded to Foster-Miller) provided for the circuitry development and engineering needed to integrate the Foster-Miller multi-parameter sensor into the existing Phase II WQAU-P and the redesign of the WQAU-P case.

The Phase III WQAU-P is shown in Figure S-1 in its closed/portable configuration. The WQAU-P weighs 6 lb and occupies 2.0 ft. The open WQAU-P with its new multiparameter sensor, existing chlorine sensor and accessories is shown in Figure S-2.

The ranges and sensitivities for each of the Phase III WQAU-P's parameters are listed in Table S-1.

The multiparameter sensor houses four of the five WQAU-P parameters (temperature, pH, TDS and turbidity). Compared to the troublesome multiparameter sensor used with the Phase II WQAU-P, this new multiparameter sensor provides the following advantages:

- Extended parametric range
- Increased accuracy
- Reduced maintenance/servicing

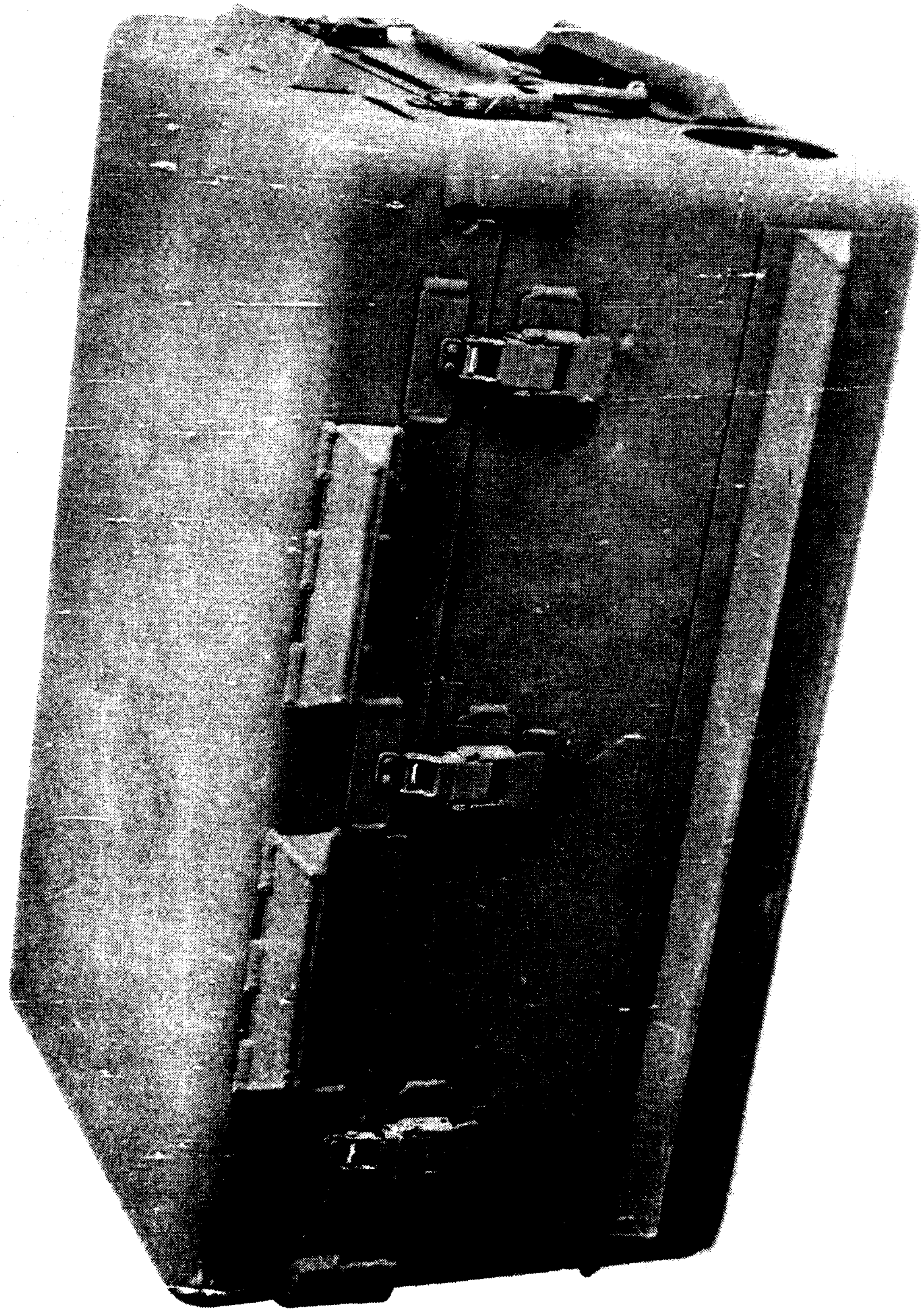

Figure S-1. WQAU-P in Closed Configuration

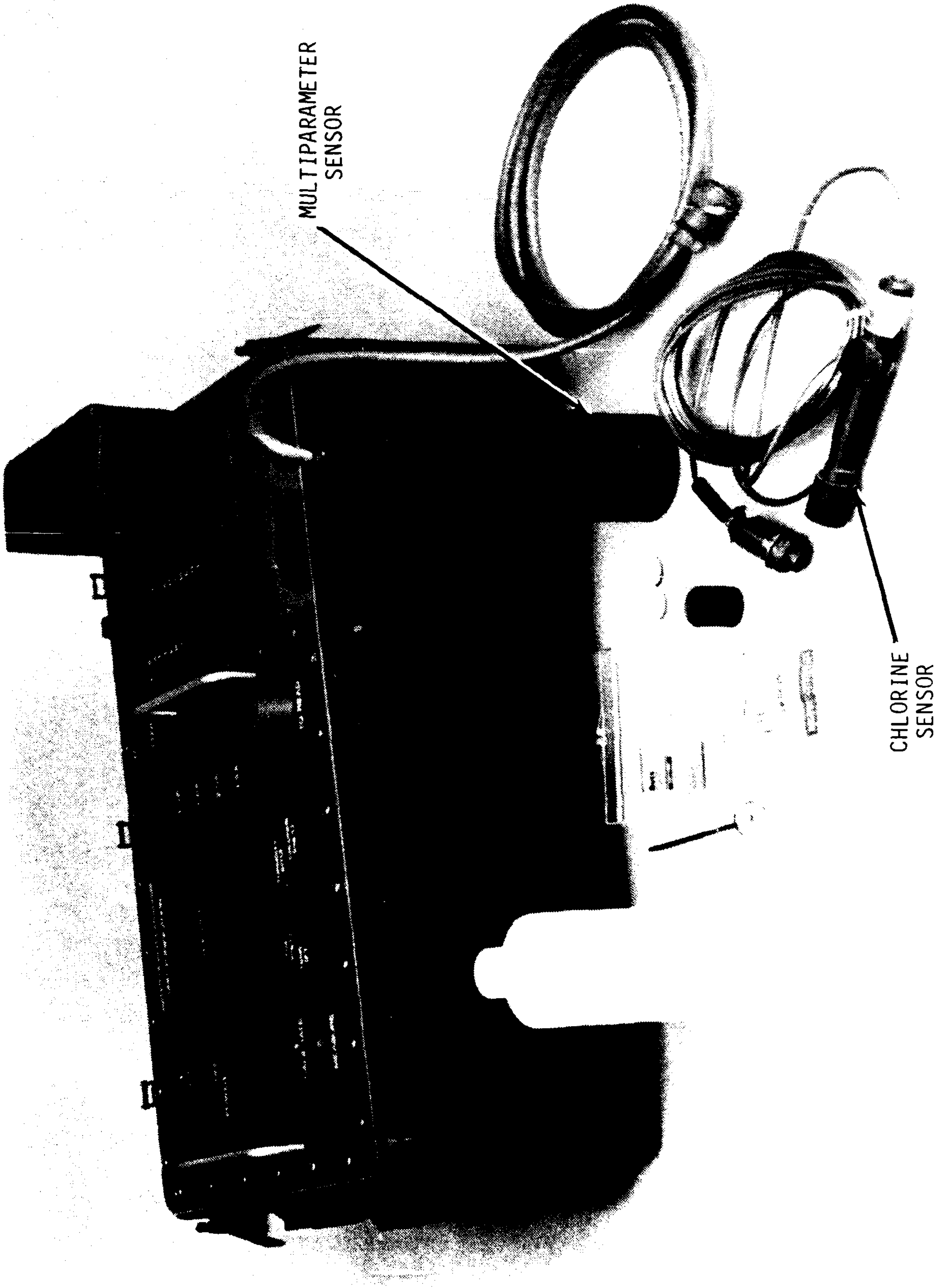

Figure S-2. WQAU-P with Top Cover Removed

Table S-1. Specifications for WQAU-P Parameters

Parameter	Range	Accuracy
Temperature (air)	0-160^{o}F	±2^{o}F
Temperature (water)	32-120^{o}F	±2^{o}F
pH	2-12 pH units	±0.5 pH units
Total Dissolved Solids	5,000-50,000 mg/l	±2,500 mg/l
	500- 5,000 mg/l	± 250 mg/l
	10- 500 mg/l	± 25 mg/l
Turbidity	0- 50 NTU	± 5 NTU
	50- 150 NTU	± 10 NTU
Chlorine Residual	1- 15 mg/l	± 1 mg/l (at pH less than 9)
(All water quality parameters must be measurable at fluid temperatures between 32^{o}F and 120^{o}F.)		

The multiparameter sensor is equipped with an outer housing that provides two functions:

- Sensor protection during storage and transport
- Calibration fluid container used during WQAU-P field calibration

The temperature, pH and TDS probes are replaceable elements. Figure S-3 illustrates the exact location of each multiparameter probe. Each of the replaceable probes are locked into the multiparameter sensor body by a spanner nut that is backed with a special gasket to provide a watertight assembly.

Since the multiparameter sensor is designed for submersible operation and does not utilize the outer housing during measurement operations, a light shield as shown in Figure S-4 is used to protect the light sensitive turbidity sensors (photodiodes) from ambient light. This light shield can be removed to accommodate sensor cleaning.

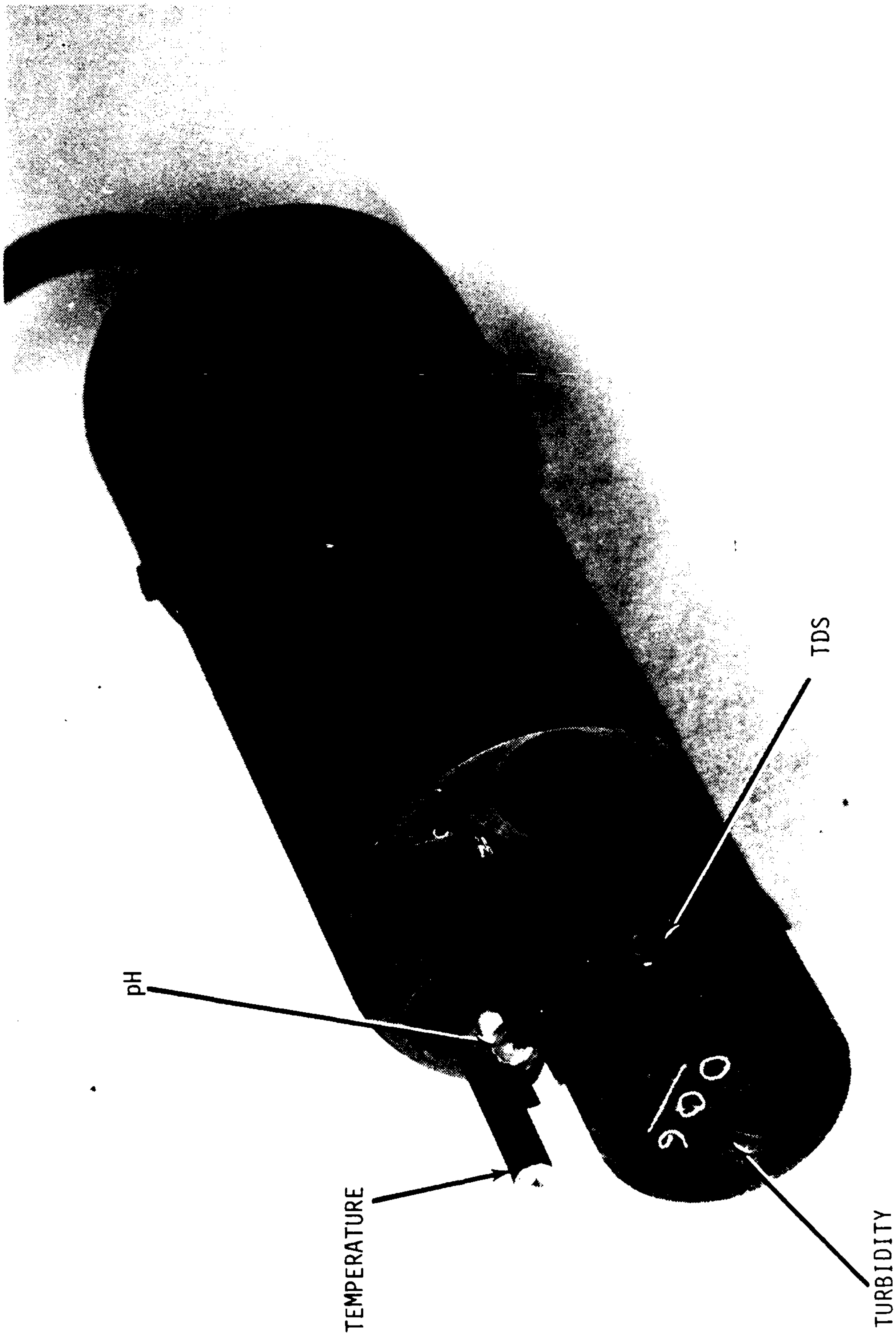

Figure S-3. Multiparameter Sensor

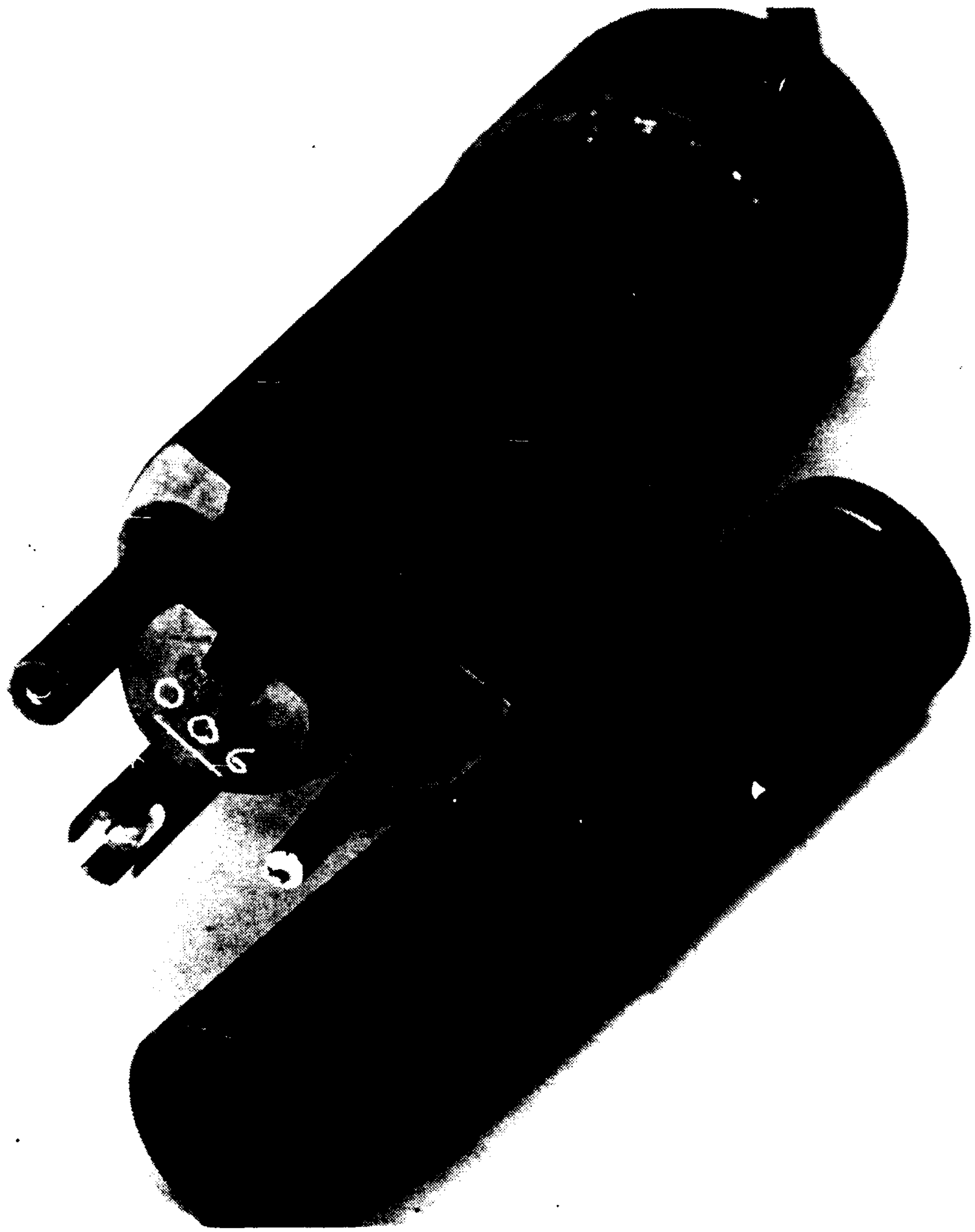

Figure S-4. Multiparameter Sensor with Turbidity Light Shield Removed

The WQAU-P case/enclosure was also modified during this contract to provide better transit drop (4 ft), EMP and chemical/biological decontamination protection. Primary modifications included:

- Adding six case latches (two each, front and back, one on each side)
- Adding guard rails to all sides of lower case and cover
- Replacing case handles with handles that lock at 90 deg for ease in handling and are spring tensioned to lie flush with case side when not in use
- Adding corner shearlocks to corners of cover
- Replacing the existing EMP gasket with a solid core silver impregnated EMP gasket
- Adding 16 control panel screws.

Operation of the WQAU-P begins with the field calibration procedure. Temperature and TDS are calibrated with dry sensors. Turbidity, pH and residual chlorine are calibrated using the only calibration fluid carried in the WQAU-P (one 500 ml bottle of buffer solution). Calibration is accomplished by setting the parameter switch to the appropriate parameter, placing the calibrate/measure switch to the calibration position, keeping the sensor dry or placing it in the calibration fluid (depending on the parameter being calibrated), and pressing the read button once for each parametric calibration.

The measurement sequence is performed by placing the appropriate sensor in the fluid to be monitored, placing the calibrate/measure switch in the measure mode, selecting the

appropriate parameter on the selector switch and pressing the read button for each measurement.

Each of the WQAU-Ps with individual multiparameter sensors were subjected to an extended matrix of tests. This validation test matrix and validation test results are summarized in Table S-2. More than 5400 measurements were taken/recorded with the Phase III WQAU-P. Over 95 percent of the readings fell within the accuracy requirements for the parametric measurements. The multiparameter sensor provided over a 97 percent accuracy rate. Residual chlorine was less impressive, logging an 89 percent accuracy rate.

Phase III WQAU-P conclusions/recommendations, as summarized below, reflect Foster-Miller's WQAU-P experience generated during fabrication, assembly, validation testing and field service activities.

- Even though 97 percent of all multiparameter sensor measurements obtained during validation testing were within the contractual accuracy tolerances, various mechanical improvements can be made to improve the sensor's performance. Components requiring redesign include:

  - The seal between the interchangeable probes and the body of the multiparameter sensor (eliminate leakage)

  - The electrical connector for the temperature and TDS probes (easier assembly)

  - The TDS probe (eliminate internal fluid trap that can cause sample contamination)

Table S-2. Summary of Validation Testing

WQAU-P/Multiparameter Sensor			1/1	3/8	6/5	7/4	5/3	4/6	Cumulative Average
Parameter	Standards Tested	Required Accuracy	Numbers of Total Readings/Percent Correct						
Temperature	320°F, 68°F 100°F, & 120°F	±2°F	83/94	78/99	78/96	84/96	86/98	84/99	493/97
Extreme Temperature	10°F, 20°F 140°F, & 160°F	±2°F	40/98	40/75	40/85	40/95	40/60	40/98	240/85
Total Dissolved Solids*	50 & 100 mg/l 500, 1,500, & 3,000 mg/l 30,000 & 50,000 mg/l	±25mg/l ±250 mg/l ±2,500 mg/l	280/100	280/98	280/93	280/100	280/100	280/100	1,680/98
pH*	4, 7 & 10	±0.5	120/100	120/100	120/100	120/100	120/100	120/100	720/100
Turbidity*	3, 10 & 50 NTU 100 & 150 NTU	±5 NTU ±10 NTU	200/99	200/99	200/98	200/89	200/97	200/90	1,200/95
Residual** Chlorine	1, 7.5 & 15 mg/l at pH 5.5 & 7.0	±10 mg/l	180/78	180/85	180/93	180/92	180/97	180/88	1,080/89

* Standards tested at temperatures of 32°F, 68°F, 100°F, and 120°F.
**Standards tested at temperatures of 32°F, 68°F, and 90°F.

  - The turbidity probe (accommodate deeper submersion into sample chamber)

  - The pH probe (protective enclosure for probe tip)

- The modified WQAU-P case with the improved EMP gasket successfully passed the EMP tests conducted at White Sands. No further action is required

- EMI, transit drop, chemical/biological decontamination and shock tests were not conducted prior to the publication date of this final report. Completion of these tests would be very useful in guiding further WQAU-P design activities

- Residual chlorine measurement technique/sensor needs to be investigated further.

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PREFACE

This report details the engineering activities that were performed in integrating the Foster-Miller multiparameter sensor into the Phase II WQAU-P developed under contract DAAK70-85-C-0022 and in modifying the outer case to improve the WQAU-P's ability to survive in harsh environments. The work has been performed by Foster-Miller, Inc. of Waltham, MA under contract DAAK70-86-C-0106 for the Fuel and Water Supply Division of the U.S. Army Belvoir Research, Development and Engineering Center.

The contract has been administered by Mr. Robert E. Tobey, Procurement Contracting Officer, and Mr. Robert S. Spratling, Contract Specialist. Technical support and assistance has been provided by Mr. Gerald Eskelund, Team Chief for the Water Technology Division, and by Ms. Janet Hall and Mr. Amos Coleman, Contracting Officer's Representatives.

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1. INTRODUCTION

The objective of this contract was to replace the Horiba multiparameter sensor that was integrated into the WQAU-P developed under contract DAAK70-85-C-0022 with a specially designed Foster-Miller multiparameter sensor that is capable of measuring temperature, pH, TDS and turbidity. To achieve this objective the existing circuitry for these parameteric measurements as well as the microprocessor software had to be redesigned/revised. The ultimate goal was the development of a WQAU-P that is capable of providing the quantitative measurements needed to establish the effectiveness of a Reverse Osmosis Water Purification Unit (ROWPU) and/or determine the treatability of a raw water source.

The desired ranges and sensitivities of each parameter, as set forth in the contract, are listed in Table 1-1.

Table 1-1. Specifications for WQAU-P Parameters

Parameter	Range	Accuracy
Temperature (air)	0 - 160°F	± 2°F
Temperature (water)	32 - 120°F	± 2°F
pH	2 - 12 pH units	± 0.5 pH units
Total Dissolved Solids	5,000 - 50,000 mg/l	± 2,500 mg/l
	500 - 5,000 mg/l	± 250 mg/l
	10 - 500 mg/l	± 25 mg/l
Turbidity	0 - 50 NTU	± 5 NTU
	50 - 150 NTU	± 10 NTU
Chlorine Residual	1 - 15 mg/l	± 1 mg/l (at pH less than 9)
Expandable Parameters		
Chloride	10 - 1,500 mg/l	± 10%
Sulfate	0 - 3,000 mg/l	± 10%
(All water quality parameters must be measurable at fluid temperatures between 32°F and 120°F)		

In addition to these parametric requirements, there were various qualitative and quantitative criteria which influenced the design of the WQAU-P multiparameter sensor. These design parameters/considerations include:

- Capable of being stored in ambient air temperatures that range from $-20^{o}F$ to $160^{o}F$

- Compatible and functional with the WQAU-P including weight and size of the configuration developed under contract DAAK70-85-C-0022

- Modular in design to permit the replacement of a single parametric sensor for troubleshooting or repair.

The six WQAU-Ps delivered as GFE to the contactor were required to meet the following criteria:

- Time to complete a complete set of analyses (except chemical agent analyses) including standardization, must be less than 5 min

- One internal battery rechargeable by 12 and/or 24V dc or 24V dc or 110 and/or 220V ac shall be capable of providing 50 complete analyses between recharging operations

- The WQAU-P case must meet the requirements of high altitude electromagnetic pulse (HAEMP) protection as defined in AR 70-60 Nuclear Survivability of Army Material and impact resistance from shock effects of transit drop as specified in MIL-STD-810D paragraph 516.3 and aerial landing of 20 G's for a duration of 75 msec

- The WQAU-P cases must have a chemical agent resistant coating

- The WQAU-P must be capable of operating in climatic categories basic and hot as defined in AR 70-38

- The WQAU-P must conform with the applicable portions of Human Factors Engineering regulations as stated in MIL STD 1472. The WQAU-P is required to be operable and maintainable by soldiers who are dressed in Mission Oriented Protective IV ensemble

- The WQAU-P control panel gasket must be improved to ensure watertight and EMI protection

- All internal components added to the WQAU-P must be in accordance with the most recent MPCAG PPSL or in accordance with MIL-P-11268.

In addition to the multiparameter sensor and WQAU-P requirements just described, the contractor was also responsible for the following studies/reports:

- Feasibility study outlining the best measurement techniques that can be added to the WQAU-P to provide chloride and sulfate capabilities

- Failure Mode Effect and Criticality Analysis

- Environmental Stress Screening Plan

- Test plan to determine the operational performance of the WQAU-P

- Test and Demonstration report documenting the results of WQAU-P testing

- Feasibility study for reduction in WQAU-P weight and size

- Maintenance and Operations Manual.

Each of these seven topics have been documented in separate reports and accordingly, are not detailed in this final report. Brief summaries, however, have been included in this document when appropriate.

Section 2 of this final report describes how the monitored parameters (standard and optional) influence/affect the functional goals of the WQAU-P (i.e., evaluate ROWPU performance and raw water treatability). Existing measurement technologies and equipment are described in Section 3. The Foster-Miller multiparameter sensor is described in Section 4. Section 5 describes the mechanical and electrical design of the WQAU-P. Section 6 details the WQAU-P calibration, measurement and maintenance routines. The WQAU-P test program and test results are summarized in Section 7. Conclusions and recommendations are presented in Section 8 and 9, respectively.

2. WQAU-P PARAMETERS

2.1 Standard Parameters

Before embarking on a functional discussion of the WQAU-P, it is constructive to review the monitored WQAU-P parameters in terms of how they:

- Affect the treatability of a raw water source by reverse osmosis
- Provide a foundation for monitoring the operation of a reverse osmosis system
- Establish the general quality of potable water

The parametric ranges and sensitivities described in this subsection are not necessarily the final ranges selected, but are what Foster-Miller feels to be ideal or most appropriate for this application.

2.1.1 Total Dissolved Solids (TDS)

This parameter provides a general indication of the level of inorganic salts in solution. Pure, deionized water has a TDS value of zero, while seawater ranges from about 35,000 mg/l in the open ocean to 41,000 mg/l in the Red Sea. (The concentration of solids in the Dead Sea ranges from 195,000 to 266,000 mg/l, but is not considered a likely source of raw water). The TDS of drinking water must be below 1,500 mg/l in accordance with TB MED 229, Sanitary Control and Surveillance of Supplies at Fixed and Field Installations, and ideally should fall in the 100 to 300 mg/l range.

A knowledge of TDS in the feed to a reverse osmosis unit is of concern as:

- High TDS means high osmotic pressure and lower production rates

- Recovery rates with high TDS waters may have to be reduced to avoid scaling

- As membrane salt rejection is (approximately) independent of feedwater concentrations, high TDS feeds may require multiple passes to achieve the desired product quality. This reduces the capacity of the reverse osmosis unit.

Membrane salt rejections range from 95 to more than 99 percent, so the permeate from a single pass reverse osmosis module may have a TDS value ranging from less than 10 for a good quality surface water feed, to several thousand for a seawater feed.

It is clear that while the range in TDS that may be encountered is wide (approximately zero to 50,000 mg/l), a knowledge of the absolute value is not critical for any of the above considerations. However, it is useful to be able to monitor small changes in permeate quality, as this can be used as a check on the condition of the membranes.

2.1.2 pH

pH is defined as the negative logarithm of the hydrogen ion concentration. It is a measure of how acidic or basic the water is. A pH of 7 is neutral, while a value of zero is the most acid end of the pH scale, and 14 the most basic. Because the scale is logarithmic, a pH of 3, for example, is 10 times

more acidic than a pH of 4. The pH of natural waters is generally in the range of 4 to 9. The pH of drinking water should be between 5.0 and 9.0 in accordance with TB MED 577.

All reverse osmosis membranes have pH limitations, and the pH further influences the degree of degradation by other agents such as iron and chlorine. Cellulose acetate membranes are hydrolyzed below pH 2 and above pH 8, while polyamide and composite membranes can be operated over a pH range of 3 to 11. As the WQAU-P is to be used with raw water supplies rather than chemical process streams, we feel that an accurate indication of pH is important in the 4 to 9 range.

2.1.3 Turbidity

Water used for drinking should be clear, with a turbidity below 5 nephelometric turbidity units (NTU) as per TB MED 577. Turbidity in the feedwater to reverse osmosis can result in rapid fouling and failure of the membranes. Hollow fiber-type membranes are particularly prone to physical blocking due to the particulate matter in the feed. It is clear that the sensitivity of the turbidity sensor should be geared towards the lower end of the range.

2.1.4 Temperature

This is an important parameter when monitoring the operation of reverse osmosis units. All membranes have temperature limits; as a general guide these are 95^{o} for polyamide membranes, $122^{o}F$ for cellulose acetate membranes, and up to $140^{o}F$ for some modern composite membranes. A lower limit of 32^{o} is usually specified. The higher the temperature, the higher the production rate, all other factors being equal. On the other hand, the rate of a chemical reaction increases exponentially with temperature, so relatively small temperature

rises can significantly increase membrane degradation rates. The required $2^{o}F$ sensitivity over a 25^{o} to $160^{o}F$ as stated in the contract specifications range should be more than adequate for protecting the reverse osmosis membranes.

2.1.5 Residual Chlorine

Free chlorine is generally not present in natural waters. It is a strong oxidant and biocide and is added during treatment to kill bacteria and oxidize undesirable chemicals such as iron and sulfides. Polyamide membranes are very sensitive to chlorine, especially at low pHs. Below pH 8, they should not be exposed continuously to more than 0.1 mg/l; while above pH 8, the limit becomes 0.25 mg/l. Composite membranes have a slightly better tolerance, and the limit for cellulose acetate membranes is set at 2 to 5 mg/l. It is clear that an accurate indication of free chlorine is needed to:

- Insure destruction of all bacteria (a dosage of 5 mg/l should provide adequate disinfection)

- Protect membranes against accidental addition of chlorine to the raw water source.

2.2 Optional Parameters

2.2.1 Chlorides

Chlorides are present in all water supplies, usually as a metallic salt (i.e., NaCl). High chloride waters are not known to have toxic effects on humans, but generally have an objectionable salty taste when present in chloride concentrations in excess of 250 mg/liter. When present as a calcium or magnesium salt, the detection level may be as high as 1,000 mg/liter.

Generally, the maximum allowable chloride concentration for public water supplies is 250 mg/liter, and is based primarily on taste criteria.

2.2.2 Sulfates

Sulfates appear in natural waters in a wide range of concentrations. On occasions, high concentrations of sulfate can have cathartic effects; however, acclimatization is very rapid. The taste threshold of magnesium sulfate is 400 to 600 mg/liter and for calcium sulfate is 250 to 800 mg/liter. Drinking water standards generally do not exceed 250 mg/liter and are based primarily on taste and laxative effects criteria.

A knowledge of the sulfate concentrations in the raw water is important for operation of the reverse osmosis module since at high concentrations of calcium sulfate, the membranes tend to foul and the addition of inhibitors is required to prevent this problem from occurring.

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3. MEASURING METHODOLOGIES

3.1 Standard Parameters

3.1.1 Total Dissolved Solids (TDS)

Instrumental determination of TDS is done by measuring the conductivity of the water sample, and relating the conductivity to a dissolved solids concentration. The relationship between conductivity and concentration varies with the type of salts present in the water, is nonlinear with concentration, and is temperature-dependent. In practice, a standard mixture of salts representative of typical natural waters is selected as the basis for the conductivity-concentration correlation, and the non-linearity and temperature-dependence are compensated for electronically.

The conductivity transducer, or conductivity cell, consists essentially of two electrodes in an insulating chamber. The water sample may either flow through the cell, or the cell may be immersed in the water. The resistance of the water between the electrodes is measured by making the cell one arm of an alternating current Wheatstone bridge. The conductivity, usually expressed in micromhos per centimeter, is the inverse of this resistance multiplied by a cell constant, which is a function of the size of the electrode/cell assembly.

A common error arising in conductivity measurements is due to the fouling of the electrode surfaces. Electrodeless systems incorporating imbedded transformer coils have been devised, and are useful for reducing calibration and maintenance requirements in adverse operating environments. Periodic calibration to ensure accuracy is nevertheless

required. The buffer solution used for pH calibration can serve as a span check for the conductivity cell. Deionized water is used as the standard for zero conductivity.

3.1.2 pH

The glass electrode is the transducer universally used to determine pH. In simplistic terms, the difference in hydrogen concentration in the water sample and in a standard solution inside the glass electrode produces a potential that can be expressed as pH. The potential must be measured relative to the standard potential of a reference electrode. In addition, the potential developed by the electrode is temperature dependent, so a knowledge of the temperature is required to accurately determine the pH. Combination electrode assemblies that house both the glass and reference electrodes, as well as a temperature sensor, are available. Automatic temperature compensation is accomplished in the signal processing section, which is basically a very high impedance voltage amplifier (millivoltmeter).

Because pH measurement is very widely used in the chemical process industry, rugged electrode systems and highly reliable electronic circuits have been developed. In addition, pH measurement is relatively free from interference, so sample conditioning is not required. However, the standard solutions in some electrode types leak slowly into the sample, so they have to be refilled occasionally. Because electrodes degrade with time, and to avoid problems associated with refilling and rejuvenating in the field, we recommend periodic replacement of the electrode assembly.

Fouling of the electrode surface and other changes in the electrodes and potentiometer can be expected to occur in normal use. These changes are corrected by calibration with buffer (fixed pH) solutions.

3.1.3 Turbidity

Turbidity is caused by suspended particles in the water and is measured quantitatively as the fraction of light that is absorbed and scattered, rather than transmitted through a sample. It is not a direct measure of the amount of suspended solids present as the absorption and scattering of a light beam is dependent on the size of the particles present, as well as on their number.

The transducer element used to measure turbidity consists of a light source, a photoelectric detector, and a cell for holding the sample. In many modern instruments, the detector is placed at 90 deg to the light path and, therefore, measures the amount of light scattered by the suspended particles. This arrangement is called a nephelometer. The nephelometric method avoids many of the errors related to particle size and solution color that arise when measuring transmitted light, and is also more accurate at low turbidities.

Periodic calibration is required to correct for changes in the strength of the light source and for other instrument variations. The zero reading can be set with deionize-demineralized water or with an empty cell. A screen or grid with known light scattering characteristics may be used to adjust the span. This method is claimed to be accurate to within 5 percent in the higher (>100 NTU) turbidity ranges, but may not be satisfactory for calibrating at low turbidities. Improved accuracy can be achieved by calibrating with a standard formazin solution, but the procedure is relatively complex and formazin has a relatively short shelf-life. A more stable turbidity standard exists which consists of suspended polystyrene beads in a water based fluid. Validation testing of this polystyrene standard is presently being conducted by Horiba, Inc.

The turbidity measured in a nephelometer is expressed in NTUs as opposed to JTUs (Jackson turbidity units) measured in an instrument measuring transmitted light. NTU and JTU units are, approximately, interchangeable. Expressing turbidity as "ppm units" derives from the method of standardizing instruments with a silica suspension of known concentration. This method is no longer used in the United States, and relating turbidity to particle concentration is not recommended.

Errors in turbidity measurement include those due to stray light reaching the detector; dirt or condensed water vapor fouling the light source, detector, or cell walls; variations in the strength of the light source; and air bubbles in the sample. Fouling problems can be reduced by scattering the light from the free (top) surface of the sample, so eliminating contact between the sample and system optics. The turbidity reading is not significantly affected by temperature, and other than eliminating air bubbles, no sample conditioning is required for the intended application.

3.1.4 Temperature

Temperature sensors suitable for instrumental monitoring may be either thermocouples or resistance thermometers. Thermocouples operate on the Seebeck principle. When the junctions of two dissimilar metals forming a closed circuit are held at different temperatures, a potential difference is generated between the junctions that can be related to the temperature difference. In order to determine the absolute temperature at the measuring junction, the temperature at the reference junction must be known. Commercial instruments are available which incorporate reference junction temperature compensation and provide direct temperature readout.

Resistance thermometers are elements whose electrical resistance varies with temperature. The platinum resistance thermometer has become an industry temperature standard, but it is not suitable for field monitoring. Thermistors are semiconductor beads that fall into the resistance thermometer category, and which are now widely used in industry for monitoring temperature. They have the advantage of small size, quick response, and provide an easily processed signal in a Wheatstone bridge configuration. Like thermocouples, they are stable and require no field calibration. Their temperature range is generally less than that for thermocouples, but still more than adequate for the WQAU-P.

3.1.5 Free Residual Chlorine

Due to the importance of chlorine measurement at municipal treatment plants, several manufacturers have developed units for continuous on-line monitoring. Three methods are in general use. The first is a colorimetric method in which an indicator (N,N-diethyl-p-phenylene-diamine or DPD) is added to the water together with a buffer to reduce pH. At low pH values, the DPD reacts with free chlorine to produce a red color. The intensity of the color is determined colorimetrically and can be expressed directly as free chlorine concentration. The same method can be used to determine total residual chlorine by additionally adding potassium iodide to the sample. The potassium iodide reacts with both free and combined chlorine releasing iodine, and the iodine reacts with the DPD indicator to produce the red color. The need to add conditioning reagents to the sample is considered to be a major drawback in applying the colorimetric method to field use.

The second method used for chlorine determination uses a specification electrode (similar in many ways to the pH electrode which may be regarded as a specific ion electrode for

hydrogen ions). Unfortunately, commercially available specification electrodes for chlorine are geared towards total residual chlorine and also require addition of conditioning reagents to the sample. Both above methods require frequent calibration.

The method we consider most appropriate to the intended application is an amperometric method. The sensor is similar to a conductivity cell described previously, but is separated from the bulk sample by a chlorine pervious membrane. Migration of the free available chlorine through the membrane produces a current between the electrodes in the cell, which is proportional to the concentration of chlorine in the sample. The current signal is temperature sensitive; and as in the case of the conductivity cell, automatic temperature compensation is provided by inclusion of a temperature sensor in the cell. Amperometric chlorine sensors are also very sensitive to pH and require appropriate adjustments based on the acid/base level of the monitored fluid.

The amperometric chlorine sensors are manufactured to operate in harsh environments with minimal maintenance and calibration requirements. Annual or bi-annual calibration may be sufficient to remain within the 1 mg/l sensitivity specification stated in the contract.

3.2 Optional Parameters

3.2.1 Chlorides

Chloride concentrations can be determined using ion specific electrodes (ISE). This type of sensor is similar to the pH electrode and its voltage signal can be processed by circuitry similar to the pH circuitry used in the WQAU-P. To the best of our knowledge, commercially available chloride ion

specific electrodes are not available with built-in reference electrodes or temperature sensors. The reference electrode typically requires periodic (weekly) maintenance.

The recommended analytical procedure for chloride ISE measurements requires the addition of a conditioning agent (ionic strength adjuster - ISA) to the water sample in equal parts. In addition, two chloride standards are also required for the generation of a semilogarithmic calibration curve of sensor millivolt potential versus chloride concentration. Due to the wide accuracy requirements set forth in this contract ($\pm$150 mg/liter), this calibration curve can most likely be preset during the detailed laboratory calibration of the WQAU-P. Generation of and reference to the calibration curve for obtaining chloride concentration measurements can be controlled by the WQAU-P's CPU. For laboratory applications this calibration curve is typically generated on a daily basis. At worst it should be possible to limit the chloride calibration fluids to one standard, as it appears that the millivolt versus concentration slope of the calibration curve remains fairly constant over a period of time.

3.2.2 Sulfates

Although there is no ISE for sulfate, a sulfate quantification procedure has been developed that utilizes a lead ISE. This procedure is relatively complex and requires the use of methanol formaldehyde and lead perchlorate. The water sample is diluted 1:1 with methanol formaldehyde solution before performing the lead perchlorate titration. The titrant is slowly added to the water sample as the titrant volume and millivolt potential of the lead electrode is carefully monitored. The point of inflection from a plot of electrode millivolt potential versus titrant volume is used to locate the end point for the titrant (ml of lead perchlorate). The

sulfate ion concentration is then calculated based on the volume of lead perchlorate added at the end point, the concentration of the lead perchlorate and the volume of water sample used before addition of methanol formaldehyde.

Colorimetric determination of sulfates is possible, but appears to be unsuitable for this application as many species interfere with the measurement. The types and number of conditioning reagents needed to evaluate a water source will vary from source to source.

The turbidimetric approach for measuring sulfates is somewhat less complicated and could utilize the existing turbidity sensor. No added sensors would be required. All signal processing could be handled by the CPU. Only software changes and minor rewiring of the WQAU-P would be required. Two reagents, however, would be required to perform the turbidity analysis for sulfate concentration. One is a liquid that is a mixture of glycerol, hydrochloric acid, water, ethyl alcohol and sodium chloride. The second reagent is barium chloride crystals.

Before sulfate readings can be obtained, a turbidity versus sulfate concentration calibration curve must be developed. Calibration curves are typically regenerated for each new batch (lot) of barium chloride. For laboratory applications the calibration curve is developed using a 5 mg of sulfate per liter of water increment. The upper concentration does not exceed 40 mg/liter, for beyond this point the barium sulfate suspension (the percipaitate that generates the concentration related turbidity becomes unstable. Sample dilution will frequently be required to obtain measurements over the desired range.

The generation of new calibration curves will probably have very little influence on the quality of the WQAU-P readings given the ±10 percent accuracy requirement for the specified range of 0 to 3000 mg/liter. Calibration curves are typically regenerated to ensure accuracies in the 1 to 5 mg/liter range.

Sample preparation is achieved by adding 5 ml of liquid reagent per 100 ml of water sample. While being agitated a spoonful of barium crystals is added to the water sample. Stirring should continue for 1 min from the time barium chloride is added. The stirring intensity should match the level of agitation that was used when generating the calibration curve.

After 1 min of stirring the turbidity is monitored for the next 4 min. The largest reading obtained during this period of time is used to calculate the sulfate concentration. The WQAU-P CPU should be able to handle this operation.

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4. MULTIPARAMETER SENSOR

4.1 Multiparameter Assembly

The Foster-Miller multiparameter sensor (shown in Figure 4-1) houses four of the five WQAU-P sensors (temperature, pH, TDS and turbidity). The basic features of this novel assembly include:

- 3 of the 4 sensors are replaceable
- The assembly is designed for submerged operation when the outer protective housing is removed
- The assembly's design philosophy can be expanded to accommodate additional sensors.

Compared to the troublesome multiparameter sensor used with the Phase II WQAU-P, the Foster-Miller multiparameter sensor provides the following advantages:

- Extended parameteric ranges
- Increased accuracy
- Reduced maintenance/servicing.

The temperature, pH and conductivity (TDS) sensors are replaceable elements, Figure 4-2 illustrates the exact location of each of these probes in the multiparameter sensor assembly. The temperature and conductivity sensors have pin socket connectors at their electrical end and are keyed to aid alignment with the mating internal pins. The pH sensor utilizes a threaded coaxial connector at its electrical end. Each of the replaceable sensors is locked into the multiparameter sensor body by a spanner nut that is backed with a

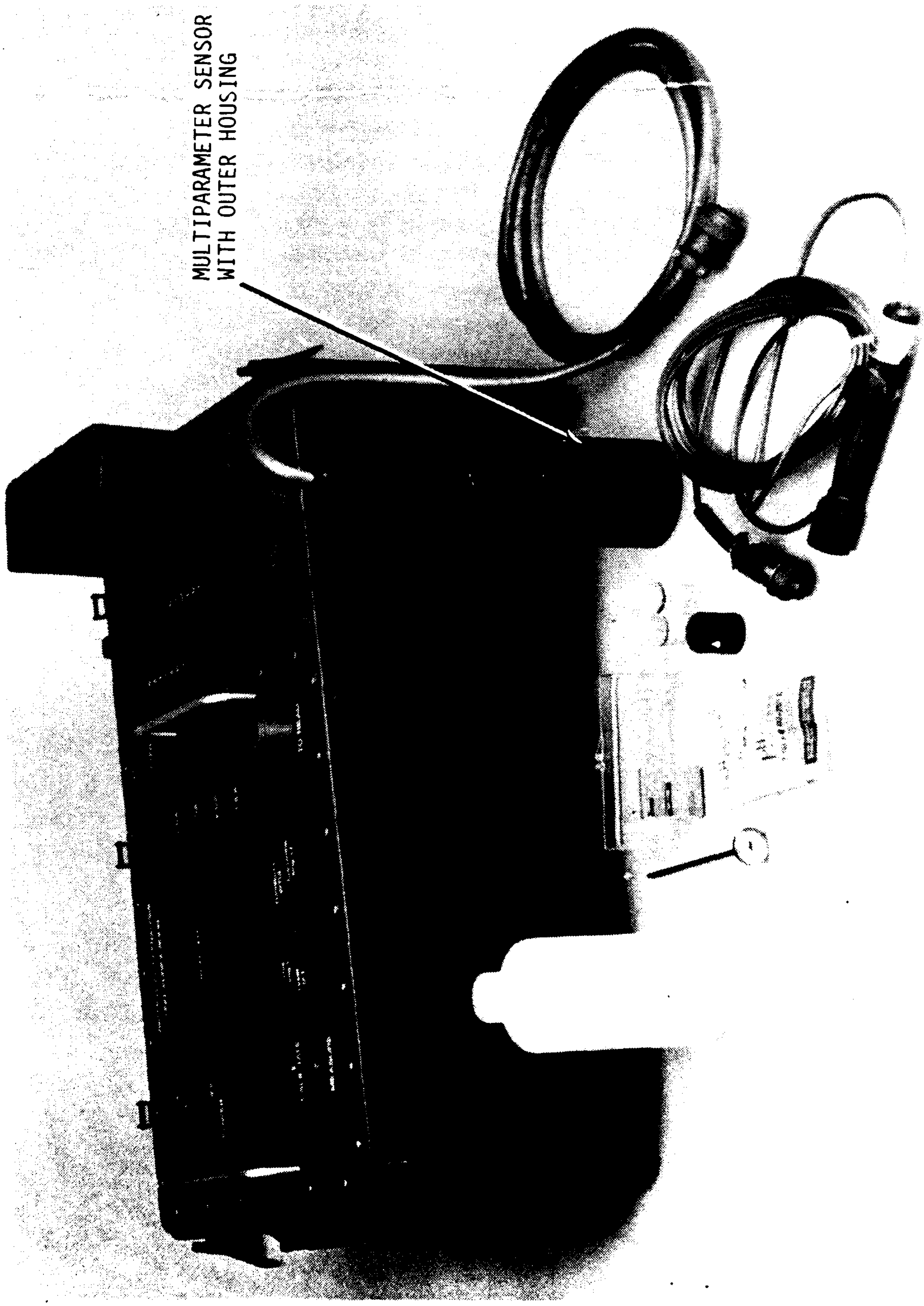

Figure 4-1. Foster-Miller Multiparameter Sensor

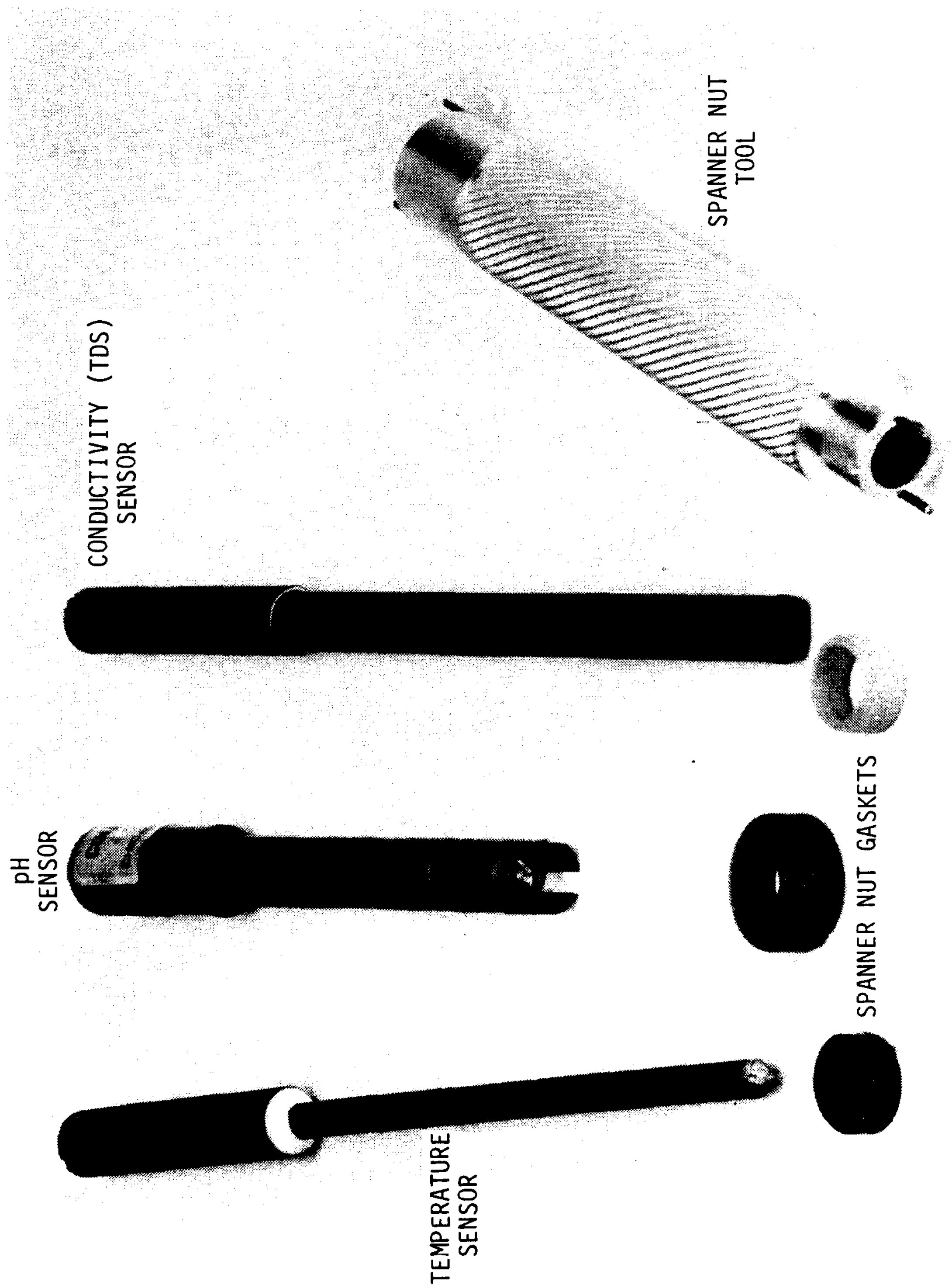

Figure 4-2. Multiparameter Sensor Components and Tool

special gasket to provide a water tight assembly. Figure 4-3 illustrates each of the replaceable sensors, the spanner nut gaskets and spanner nut tool.

The turbidity sensor has not been designed as a replaceable element. There are several reasons for this design approach.

- Sealing this large diameter sensor against water leakage is difficult; this in turn could lead to decreased reliability

- A cumbersome connector would be required to accommodate the seven active leads of the turbidity probe. Enhanced multiparameter sensor reliability is attained by molding the turbidity sensor and multiparameter assembly as one integral unit

- The turbidity probe is a molded assembly and cannot be repaired

- The cost of the turbidity probe is a large fraction of the total cost of the multiparamter sensor assembly.

Should the turbidity probe fail, the three repalceable sensors are removed and the turbidity probe and sensor assembly are discarded as a single component.

Although the multiparameter sensor is designed for submersible operation it still comes equipped with an outer housing that provides two functions.

- Sensor protection during storage and transport

- Container for holding the single WQAU-P calibration fluid used during WQAU-P field calibration.

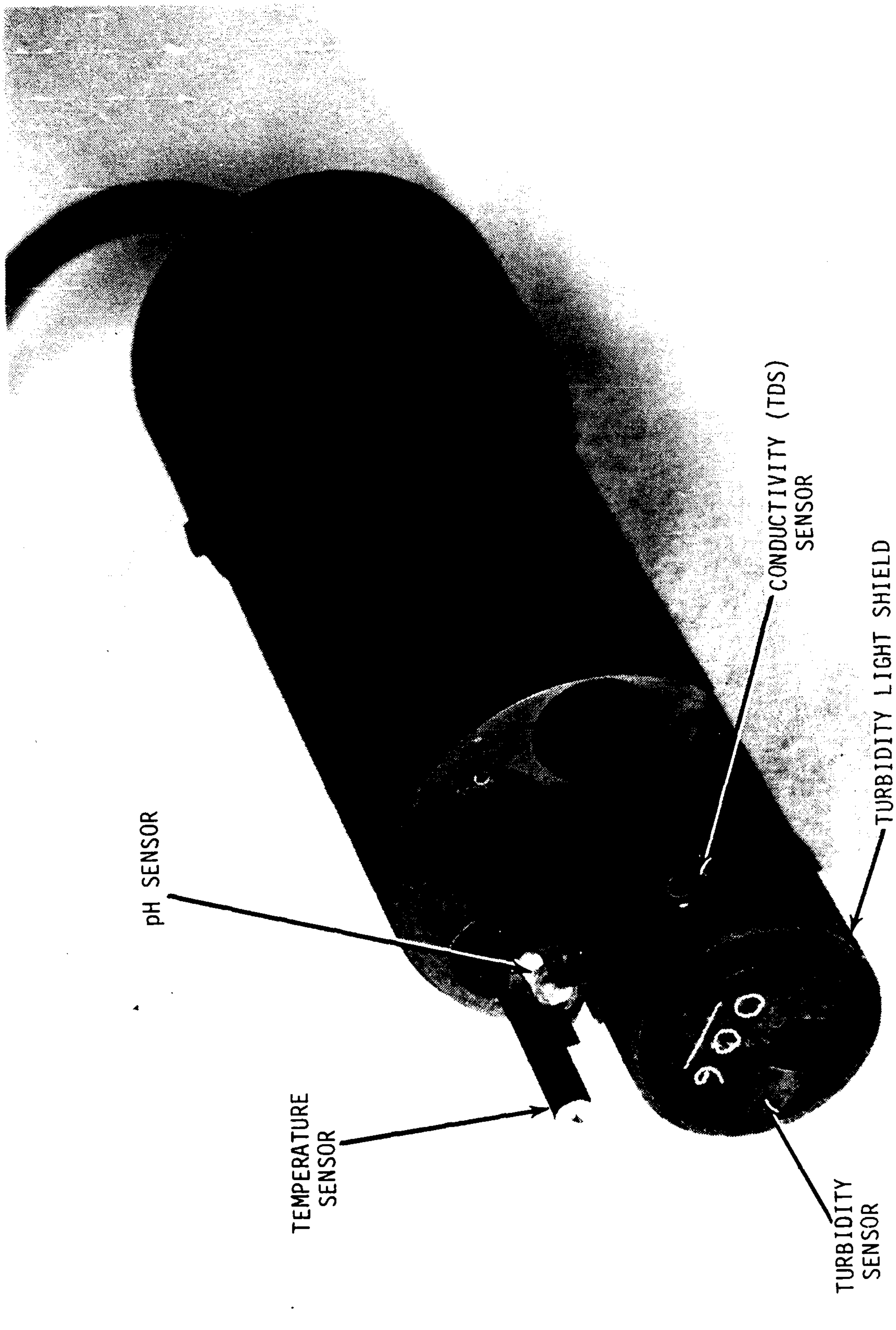

Figure 4-3. Location of Sensor Elements

The housing should always be removed when making an in situ measurement. This is the normal operating procedure to ensure that all sensors reach thermal equilibrium with the water sample. Since the multiparamter sensor is designed to operate without the protective housing, a removable light shield as shown in Figure 4-4 is used to protect the turbidity sensor from ambient light. This is removeable to accommodate turbidity sensor cleaining.

4.2 Multiparameter Sensors

4.2.1 Total Dissolved Solids (TDS)

The conductivity cell used by Foster-Miller (Figure 4-5) in their multiparameter sensor consists of two electrodes and an internal negative temperature compensation thermistor (NTC) for temperature compensation to within $\pm 2^{\circ}F$. Both electrodes are located in the inner open core of the sensor's epoxy housing. This open core passes through the entire length of the sensor and allows displaced air to be vented during sensor submersion. Specifications for the conductivity sensor are as follows:

- Operating range - 0 - 2000 µohms/cm
0 - 20,000 µohms/cm
0 - 200,000 µohms/cm
- Temperature range - 32 - $180^{\circ}F$
- Accuracy - ±2% of full scale
- Length - 6 in.
- Diameter - 0.375 in.

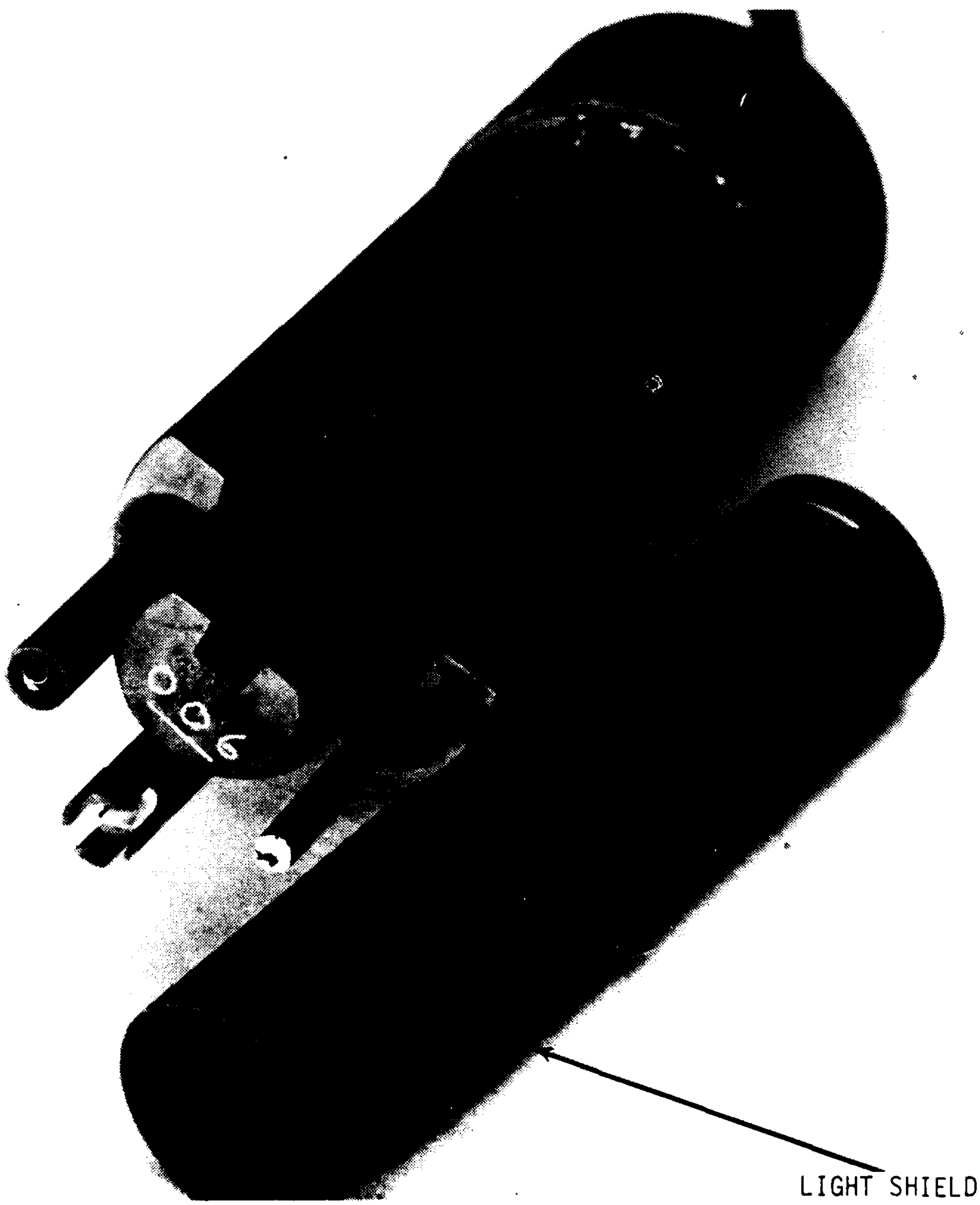

Figure 4-4. Multiparameter Sensor with Turbidity Light Shield Removed

Figure 4-5. Conductivity (TDS) Sensor

It is important to note that the conductivity of a salt solution varies with temperature. The conductivity reading provided by this sensor must, therefore, be converted to a concentration based on a particular salt. For the WQAU-P the reference salt is NaCl. The relationship between conductivity and NaCl concentration is temperature dependent. This well established relationship has been converted into an algorithm that is handled by the WQAU-P's CPU. Details are provided in subsection 5.5.2.

4.2.2 pH

The pH sensor selected by Foster-Miller (Figure 4-6) is a combination type probe that includes a glass measuring electrode and a Ag-AgCl reference electrode in one sensor body. The outer shell of this sensor is constructed from a rugged epoxy plastic that extends beyond the sensing bulb to protect the sensor against damage. This permanently sealed sensor is filled with a 2 M KCl gel that is saturated with AgCl. Specifications for the pH sensor are:

- Operating range - 0 to 14 pH
- Temperature range - 32 to 180^{o}F

Figure 4-6. pH Sensor

- Accuracy - ±0.02 pH within 3.0 pH units of calibration point
- Length - 5 in.
- Diameter - 0.5 in.

4.2.3 Turbidity

The turbidity sensor pictured in Figure 4-7 is a specially fabricated submersible probe. This turbidity probe features:

- No moving parts - low maintenance
- Practically insensitive to film build-up on sensor windows
- High ambient light rejection (achieved electronically)
- Long life due to 100% solid state circuitry.

The probe is constructed from a filled epoxy resin with a fixed reinforcing member through the length of the probe for rigidity. At either end the optical components are fixed in a

Figure 4-7. Turbidity Sensor

translucent resin that includes a light diffusing material for the windows.

Process specifications are as follows:

- Operating fluid temperature - 28 to 180^{o}F
- Operating ambient temperature - -58 to 150^{o}F
- Measuring range - 0 to 20 NTU minimum, 0 to 4000 NTU maximum.
- Accuracy - to within less than 1.0% full scale
- Optics - two 880nm light emitting diodes near-infrared range; two silicon photodiodes with interference filters limiting spectral response to 880nm $\pm$20 nm.

This turbidity sensor uses a four beam alternating light principle to negate the effects of variations in light source intensity, variations in the sensitivity of the photocell diodes and build-up of solids on the sensor windows. This four beam principle which is discussed below in detail provides a truly self-compensating turbidity sensor.

4.2.3.1 <u>Four Beam Theory</u>

The Lamber-Beer Law shows that the light lost during transmission through a medium is proportional to the concentration of the medium. The Lamber-Beer Law as applied to this sensor can be expressed as:

$$I_T = LS\ e^{-CD}$$

where

I_T = light transmitted through water sample
L = light source intensity
S = detector sensitivity
C = concentration (turbidity) of water sample
D = distance between light source and dector

Note that if L or S changes, the measurement will change. The effects of the light source and detector must be eliminated in order for the measurement to be accurate.

Figure 4-8 shows the physical arrangement of the turbidity sensor elements. Note that the distances D and d are precisely fixed.

Four discrete measurements can be obtained where I_{xy} equals the light transmitted from LED x and picked-up by detector y.

$$I_{1,1} = L_1S_1\ e^{-CD}$$
$$I_{1,2} = L_1S_2\ e^{-Cd}$$
$$I_{2,1} = L_2S_1\ e^{-Cd}$$
$$I_{2,2} = L_2S_2\ e^{-CD}$$

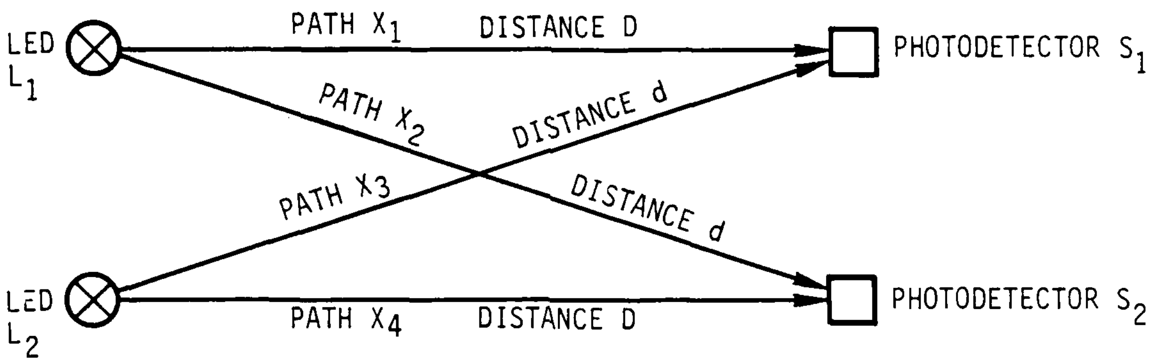

Figure 4-8. Four Beam Turbidity Sensor (Arrangement of Elements)

These four discrete measurements are obtained by cycling the light sources and photoelectric diodes in an appropriate sequence.

To eliminate the characteristics of the light sources, $I_{1,1}$ is divided by $I_{1,2}$ and $I_{2,1}$ is divided by $I_{2,2}$:

$$\frac{I_{1,1}}{I_{1,2}} = \frac{L_1 S_1 \; e^{-CD}}{L_1 S_2 \; e^{-Cd}} = \frac{S_1 \; e^{-CD}}{S_2 \; e^{-Cd}}$$

$$\frac{I_{2,1}}{I_{2,2}} = \frac{L_2 S_1 \; e^{-Cd}}{L_2 S_2 \; e^{-CD}} = \frac{S_1 \; e^{-Cd}}{S_2 \; e^{-CD}}$$

The detector sensitivity is eliminated by rearranging the last two equations as shown

$$\frac{I_{1,1}/I_{1,2}}{I_{2,1}/I_{2,2}} = \frac{S_1 \; e^{-CD}}{S_2 \; e^{-Cd}} \times \frac{S_2 \; e^{-CD}}{S_1 \; e^{-Cd}} = \frac{e^{-2CD}}{e^{-2Cd}}$$

Taking the logarithm of the above equation

$$2C(d-D) = \ln \left[\frac{I_{1,1} \quad I_{1,2}}{I_{2,1} \quad I_{2,2}}\right]$$

Since d and D are constants, water turbidity (C) can be calculated from the four light transmission valves measured by the photoelectric diodes.

Ambient light is also eliminated from the measurement process by monitoring the light that is picked up by the photoelectric diodes when the light sources are off. The influence of fluid color is also eliminated as the probe LEDs (light sources) use a near infrared light which is not absorbed by common organic or inorganic compounds.

Foster-Miller conducted a detailed laboratory analysis of the selected turbidity sensor. Five NTU samples were monitored for turbidity over a fluid temperature range of 40 to 120°F. The results of this analysis are graphically displayed in Figure 4-9. Although the turbidity readings are influenced by the sample temperature, it appears that the dependence is independent of sample turbidity. The characteristic slope of the turbidity sensor remains constant at approximately 10 NTU/80°F. This relationship was incorporated into the WQAU-P microprocessor as a corrective algorithm to provide a ±2 NTU accuracy over a turbidity range of 0 to 150 NTU and a temperature range of 32 to 120°F.

4.2.4 Temperature

The selected temperature sensor (Figure 4-10) is a dual precision thermistor. The probe's outer housing is fabricated from a rugged plastic epoxy. Performance specifications for this probe are:

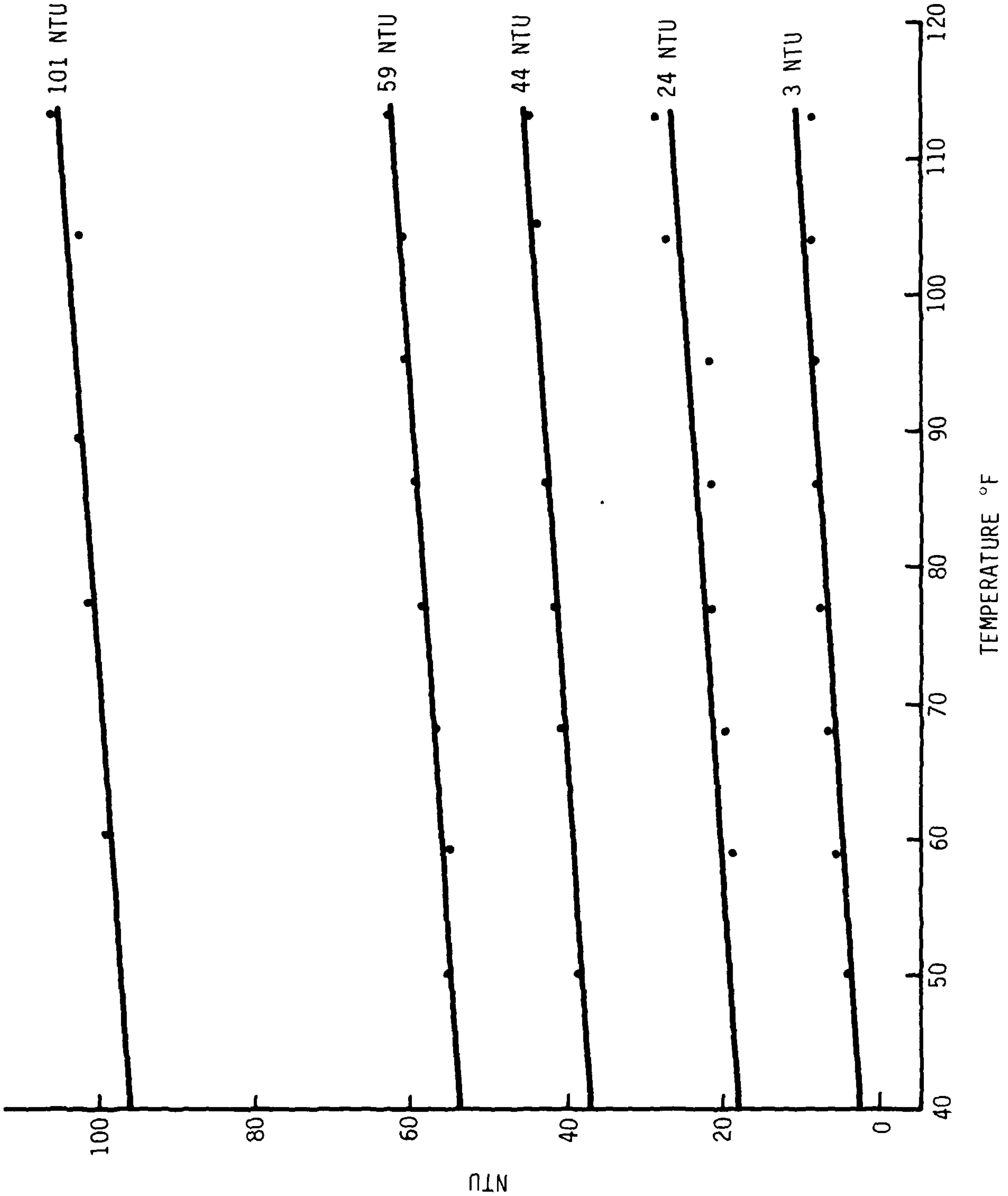

Figure 4-9. Influence of Fluid Temperature on Turbidity

Figure 4-10. Temperature Sensor

- Operating range - 5 to 180°F
- Accuracy - ±0.3 $^{\circ}$F
- Length - 6 in.
- Diameter - 0.25 in.

When testing fluids the maximum response time should not exceed 10 seconds. Response time when measuring air should not exceed 30 seconds.

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5. WQAU-P DESIGN

The WQAU-P is an assembly of specialized water measurement sensors that have been combined with a state-of-the-art microprocessor to form a simple-to-operate water monitoring instrument. Personnel experienced in the operation of the WQAU-P can typically perform a complete calibration and measurement sequence in less than 5 min.

The WQAU-P measures five parameters critical to establishing the effectiveness of a reverse osmosis water purification system or determining the treatability of a raw water source. These process parameters include temperature, pH, total dissolved solids (TDS), turbidity and free available residual chlorine.

The following subsections detail the WQAU-P's parametric and design specifications, mechanical design, electrical design and programming algorithms used for temperature and/or pH corrections. A detailed listing of the WQAU-P software is presented in the Appendix.

5.1 WQAU-P Specifications

Specification for the WQAU-P have been divided into two categories:

- Parametric Specifications
- Design Criteria.

5.1.1 Parametric Specifications

The parametric specifications for the WQAU-P in terms of range and sensitivity are presented in Table 5-1. These

Table 5-1. Specifications for WQAU-P Parameters

Parameter	Range	Sensitivity
Air Temperature	0-160	$\pm 2^{o}F$
Fluid Temperature	32-120	$\pm 2^{o}F$
pH	2-12	$\pm$0.5 pH units
TDS	0-500 mg/l 500-5,000 mg/l 5,000-50,000 mg/l	$\pm$25 mg/l $\pm$250 mg/l $\pm$2500 mg/l
Turbidity	0-50 NTU 50-150 NTU	$\pm$5 NTU $\pm$10 NTU
Free Available Residual Chlorine	0-15 mg/l	$\pm$1 mg/l (at pH less than 9)

ranges/ sensitivities reflect the expressed needs of the user community for adequately measuring raw and processed water.

5.1.2 Design Criteria

To accommodate simplicity of operation and the need for a rugged field portable instrument, there were a number of physical constraints placed on the WQAU-P design. The design goals (criteria) for the WQAU-P are listed in Table 5-2.

5.2 Mechanical Design

The WQAU-P is housed in an aluminum carrying case as shown in Figure 5-1. Manufactured by Zero Corporation, the basic

Table 5-2. WQAU-P Design Criteria

Physical Constraints
Moisture proof design
Parameter selector switch to coincide with logical sequence of parametric measurements
Five digit display
Battery can be replaced without opening the electrical compartment
Main system fuses accessible from front control panel
Battery recharge can be accomplished while unit is in its storage configuration
Survive an EMP while in the closed configuration
Survive shock effects from aerial landing and 4 ft drop
Survive NBC decontamination while in the closed configuration
Protected from emitting a distinctive electronic signature or interfering with electrical communication as per MIL STD 461A
Protected from damaging effects of nuclear, biological and chemical contamination
Operational in climatic categories basic and hot (AR 70-38)
Electrical Constraints
Powered by internal battery (4 to 8 hr continuous operation)
Rechargeable from 110 and 220V, 50-60 Hz ac, and 12 and 24V dc
Safety feature to prevent battery overcharge
Internal autoranger for TDS ranges
Error trapping routine to eliminate stray readings
Provide a trickle charge to chlorine sensor while in the storage configuration

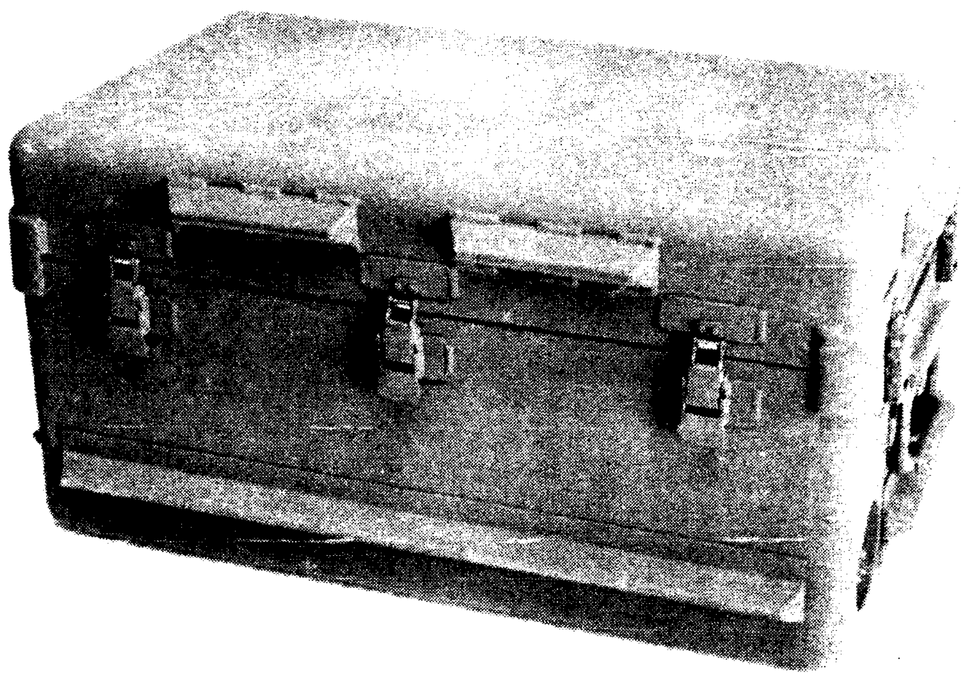

Figure 5-1. WQAU-P in Closed Configuration

outer case features high strength, relatively lightweight and clean outer lines with seamless construction. The upper lid (cover) is sealed by a fully gasketed tongue and groove closure providing EMP protection (when equipped with the appropriate gasket) and is secured by positive locking latches on the front, sides and rear. This 13 in. wide by 22.5 in. long by 12 in. high case occupies 2.0 ft^3 and weighs 44 lb.

The outer case was modified during this contract to provide better transit drops (4 ft) protection. Outer case modifications included:

- Adding one case latch at the center of the front and back side, and adding two latches on each end (short length)

- Adding guard rails to all sides of the lower case (Figure 5-2)

- Adding modified guard rails to all sides of the cover

- Replacing case handles with militarized handles as shown in Figure 5-3. Handles lock at 90 deg for ease in carrying and are spring tensioned to lie flush with the side wall of the case when not in use

- Adding corner shearlocks on all four corners to keep cover from moving during impact.

The inner case was also modified during this contract to provide better EMP protection, water leakage protection and EMI protection. These modifications included:

- Replacing the existing EMP case gasket, a wire mesh covered hollow tube, with a solid core circular cross section gasket that is impregnated with silver

PERFORMANCE DATA: Provides protection per MIL-T-21200 and MIL-T-28800.

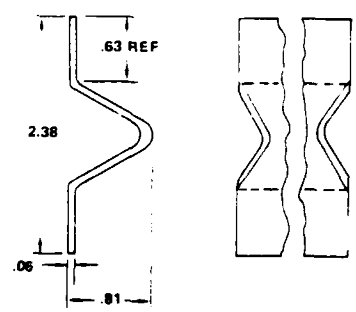

Figure 5-2. Case Guard Rails

PERFORMANCE DATA: provides protection for handle per MIL-T-21200 and MIL-T-28800. Self-contained protection reduces case weight and provides easier fabrication.

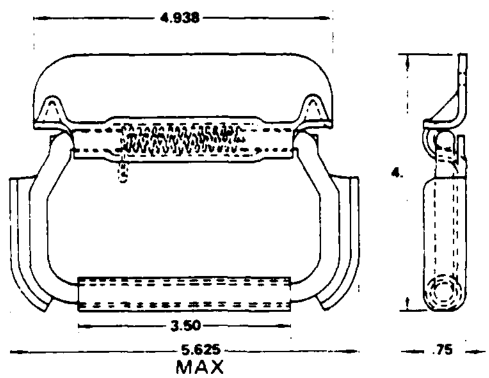

Figure 5-3. Case Handles

- Replacing the existing rubber control panel gasket with a combination foam and EMI wire mesh gasket

- Adding 16 hold down screws to the control panel.

The WQAU-P is divided into two compartments:

- Sensor/Accessory
- Electrical.

When the WQAU-P cover is removed, the control panel and accessory compartment are exposed (Figure 5-4).

5.2.1 Sensor/Accessory (S/A) Compartment

The S/A compartment houses both measurement sensor (multi-parameter and residual chlorine), power cords (ac and dc), battery, sensor connectors and an assortment of field calibration and field maintenance accessories. S/A components are shown in Figure 5-5.

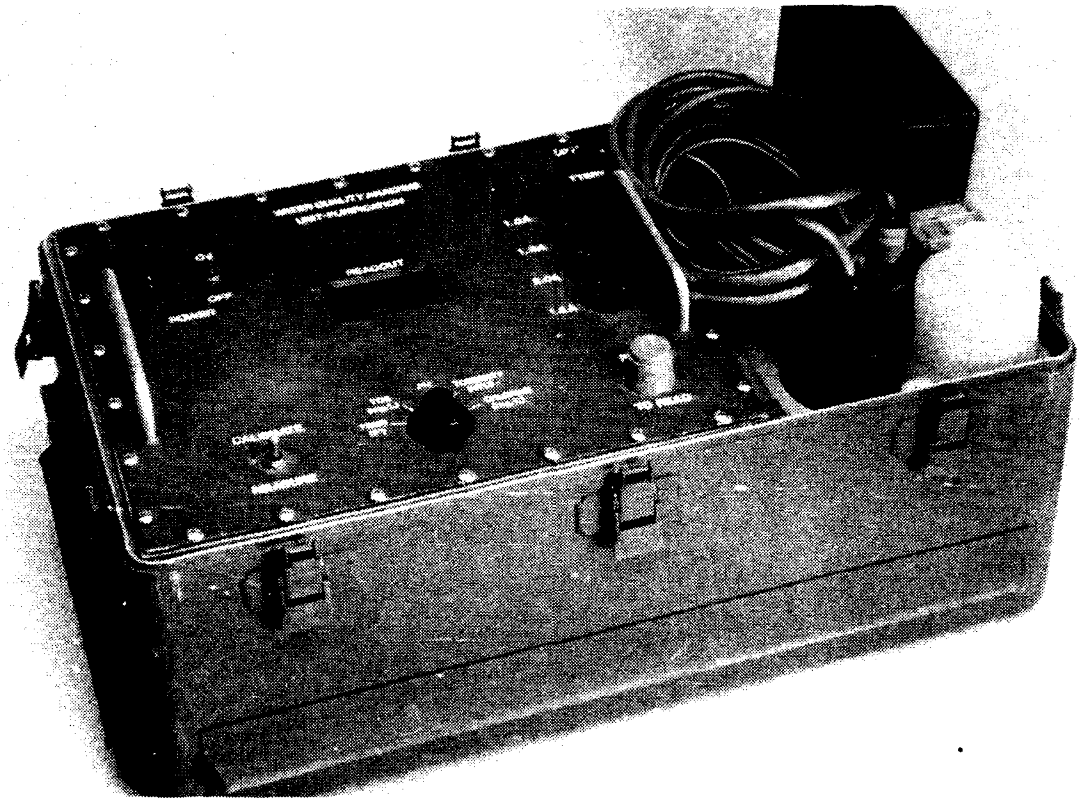

Figure 5-4. *WQAU-P with Top Cover Removed*

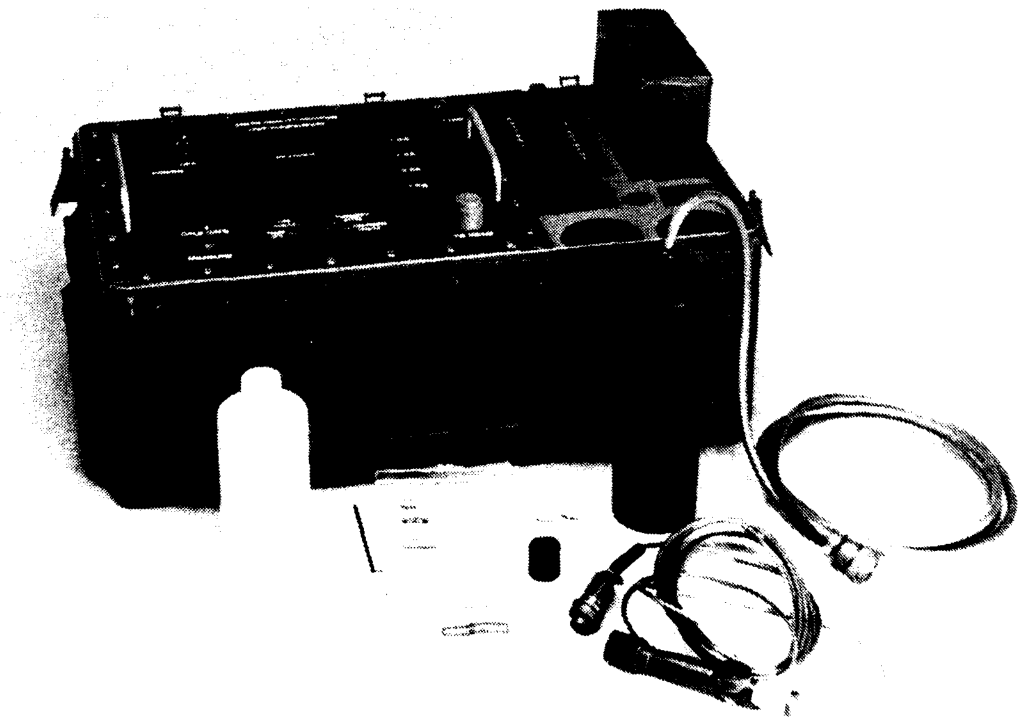

Figure 5-5. WQAU-P Sensors/Accessories

5.2.1.1 Sensors

The multiparameter sensor has been described in detail in Section 4.

The free available residual chlorine sensor is shown in Figure 5-6. The probe is composed of a PVC body, gas permeable membrane, gold cathode and silver anode. The sensor is provided with a screw-on membrane tip for easy maintenance. A red snap-on cap protects the sensor membrane during storage and transportation. This cap must be removed prior to making measurements.

The residual chlorine sensor requires a flow of fresh sample at the probe tip. During measurement operations, this sensor must be moved through the sample at a velocity of 1 ft/sec. A figure "8" motion can be used to meet this requirement.

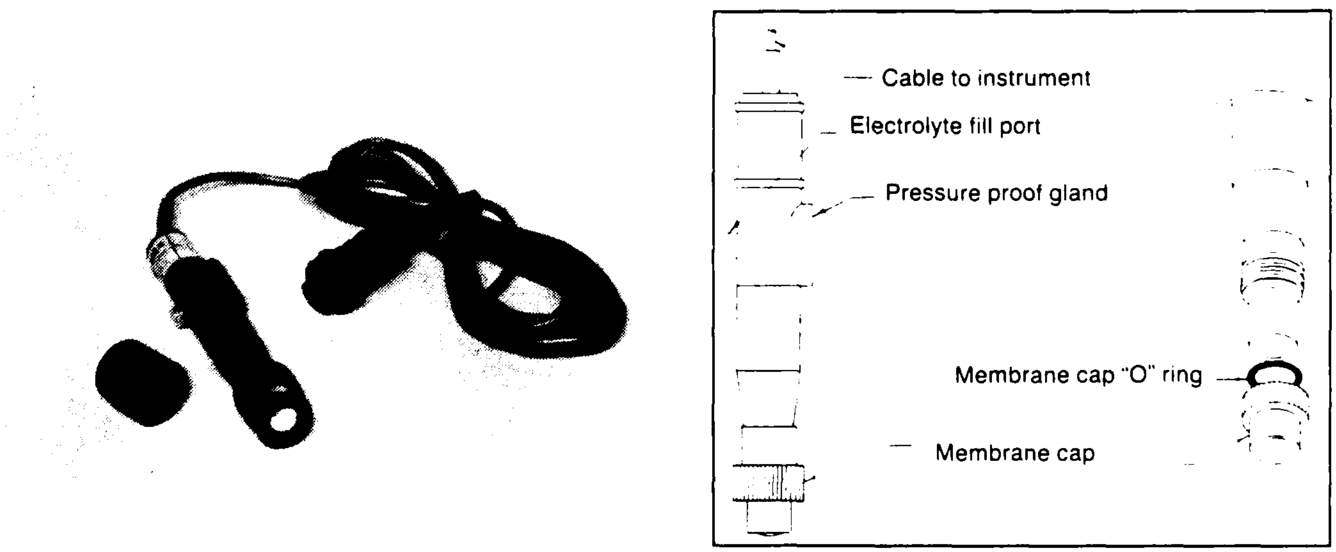

Figure 5-6. Free Available Residual Chlorine Sensor

The chlorine probe is passive-type sensor and must not be removed from its terminal connector. If disconnected or if the battery is removed from the WQAU-P, the sensor must be allowed to stabilize for at least 30 min after it has been reconnected or the battery has been replaced.

5.2.1.2 Main Battery

The WQAU-P's internal power source is a 4.0 Ahr 12V rechargeable nickel cadmium (NiCd) battery (Model No. PAD1252TAL3, manufactured by Adcour Inc., of Sharon, MA). When fully charged this battery will provide approximately 12 hr of continuous operation. A 24 hr recharge period is required to fully charge a battery that has activated the low level battery light. If the low level battery light comes on, the WQAU-P will remain operational for approximately 30 min. The present cycle of measurements can be completed.

The main battery is housed in a water tight compartment positioned within the S/A compartment. The battery can be easily replaced/removed by loosening the two thumb screws and pulling the entire holder up.

5.2.1.3 Accessories

Accessories contained within the WQAU-P include:

- Power cords (110V ac, 220V ac and 12/24V dc)
- 500 ml bottle of buffer solution
- Electrolyte for residual chlorine sensor (R-448)
- Powered buffer packets pH = 7.0
- Control panel fuses.

5.2.1.4 Connectors

Connectors for the multiparameter and residual chlorine sensors are located on the inner side panel of the S/A compartment. Figure 5-7 illustrates the multiparameter sensor connector. The residual chlorine connector is directly below the multiparameter sensor connector. The external power connector is recessed on the outer side of the S/A compartment as shown in Figure 5-8.

5.2.2 Electrical Compartment

The top side of the electrical compartment is the WQAU-P control panel. This control panel as shown in Figure 5-9 houses all operating controls, displays and fuses. Specifically this includes:

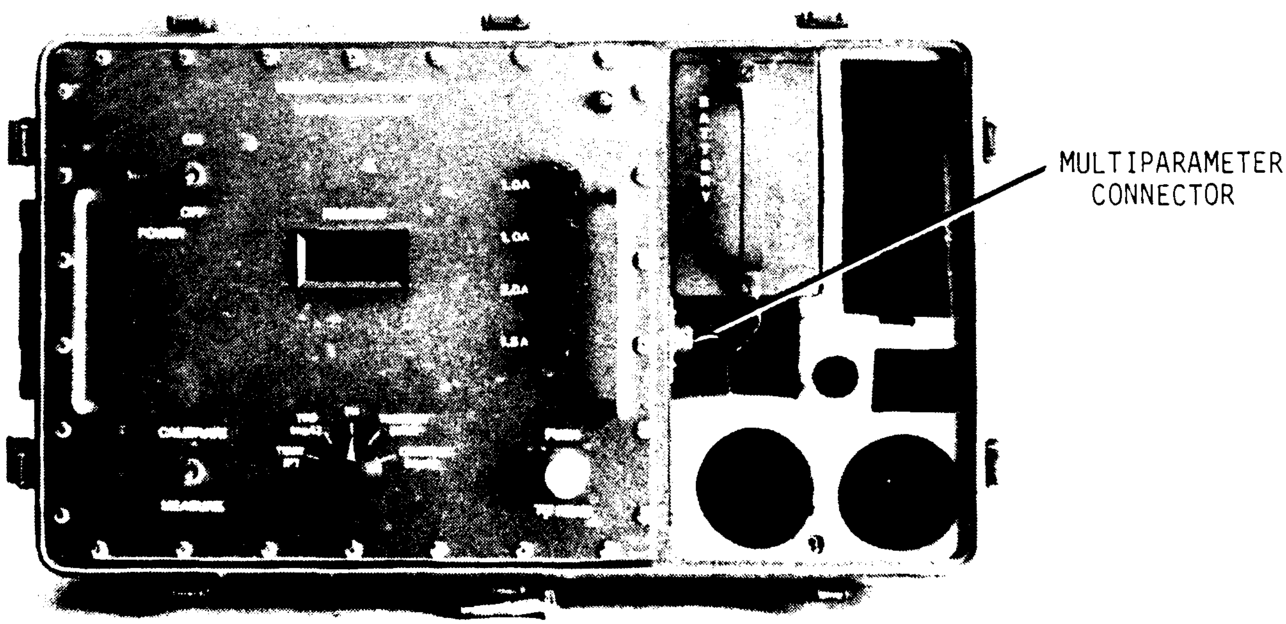

Figure 5-7. Multiparameter Sensor Connector

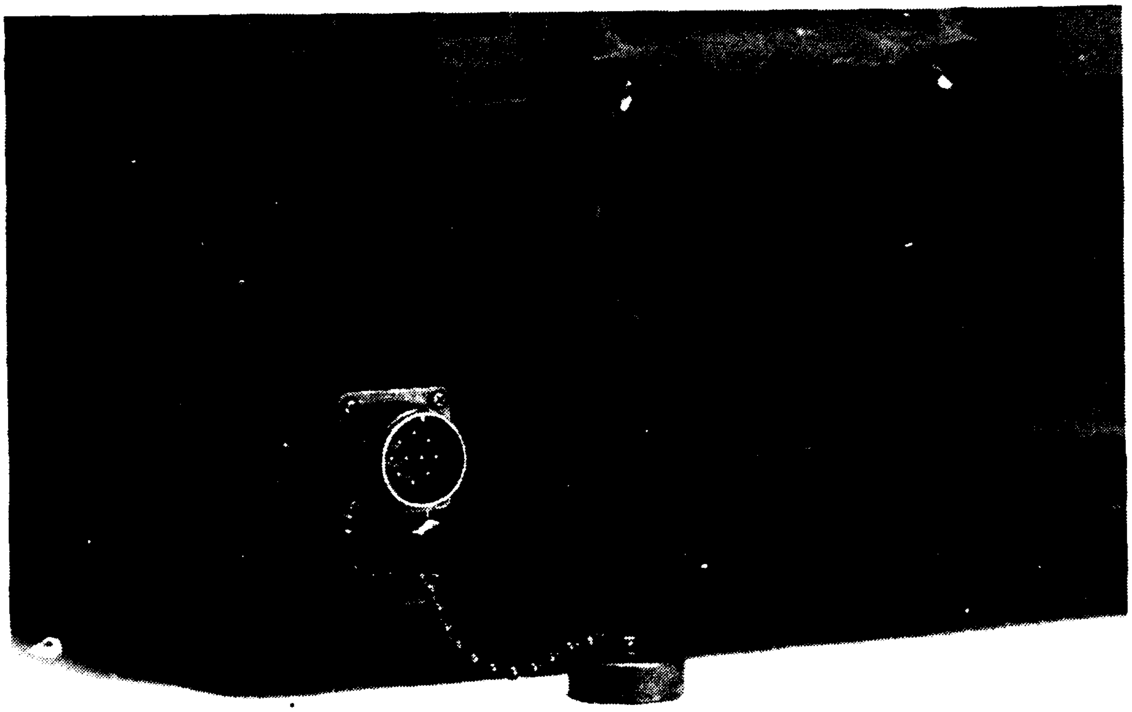

Figure 5-8. WQAU-P Power Connector

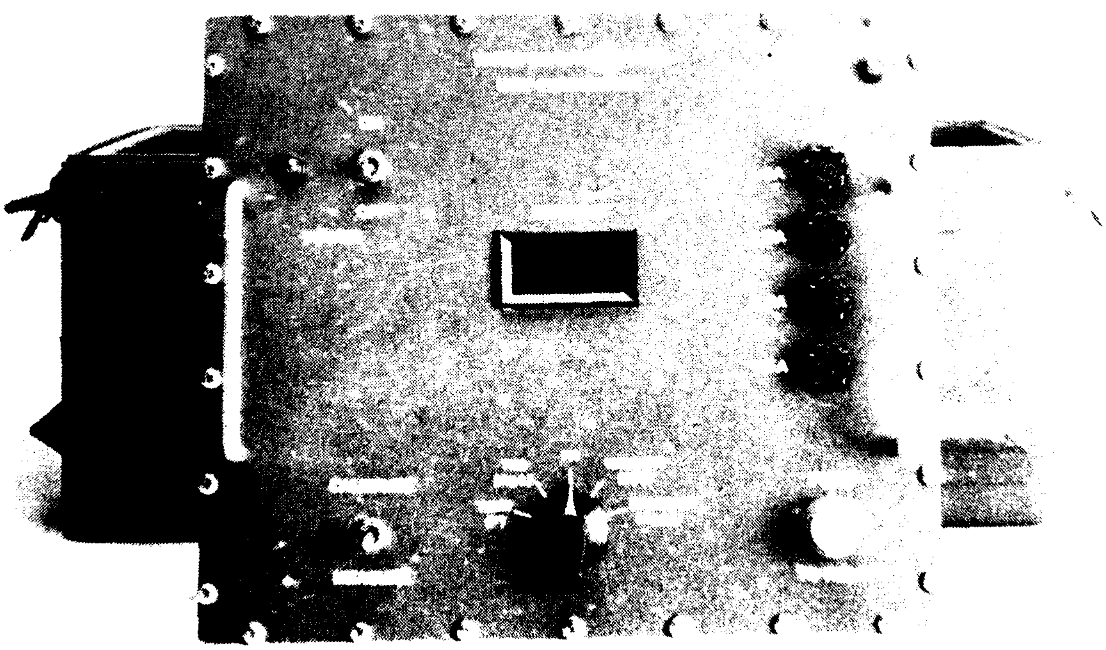

Figure 5-9. Control Panel

Operating controls

- Power switch (on-off)
- Mode switch (calibrate/measure)
- Parameter selector switch
- Push to read button

Displays

- Five digit LED readout
- Power on light
- Low battery light

Fuses

- Two 1.0A ac power fuses
- One 2.0A dc power fuse
- One 1.5A display fuse

The control panel is equipped with two handles for easy removal of the WQAU-P's electronics from the Zero case. When the control panel is removed, all WQAU-P circuitry becomes easily accessible for servicing. All circuit boards requiring adjustments are attached to the outside of the main card cage assembly. This card cage assembly is attached to the control panel with shock mounts for the purpose of protecting all circuitry. The card cage internally houses the CPU board, the I/O board and the memory expansion board. Boards attached to the outside of the card cage assembly include:

- Sensor control circuit board
- Power supply circuit board.

5.3 Electrical Design

The electrical assembly of the WQAU-P consists of several components/subsystems. They are:

- Sensor control circuit board
- Display circuit board
- I/O circuit board
- CPU circuit board
- Memory expansion circuit board
- Power supply circuit board and accessories
- Operator controls.

5.3.1 Sensor Control Circuit Board

The sensor control circuit board provides the signal path between the microprocessor and the measurement systems. It informs the microprocessor which parameter is being monitored and which operating mode is being activated.

The control circuit board contains all the measurement processing circuitry, parametric adjustments and analog to digital conversion circuits that convert the measurement analog voltages to a digital representation for processing by the microprocessor.

All connections to and from the control circuit board are made through ribbon cables and connectors.

The electrical schematic of the control circuit board is shown in Figures 5-10 and 5-11.

The following paragraphs under this subsection describe each of the parametric measurement circuits. Sensor electronics are also discussed when appropriate to provide additional insight as to how each circuit functions.

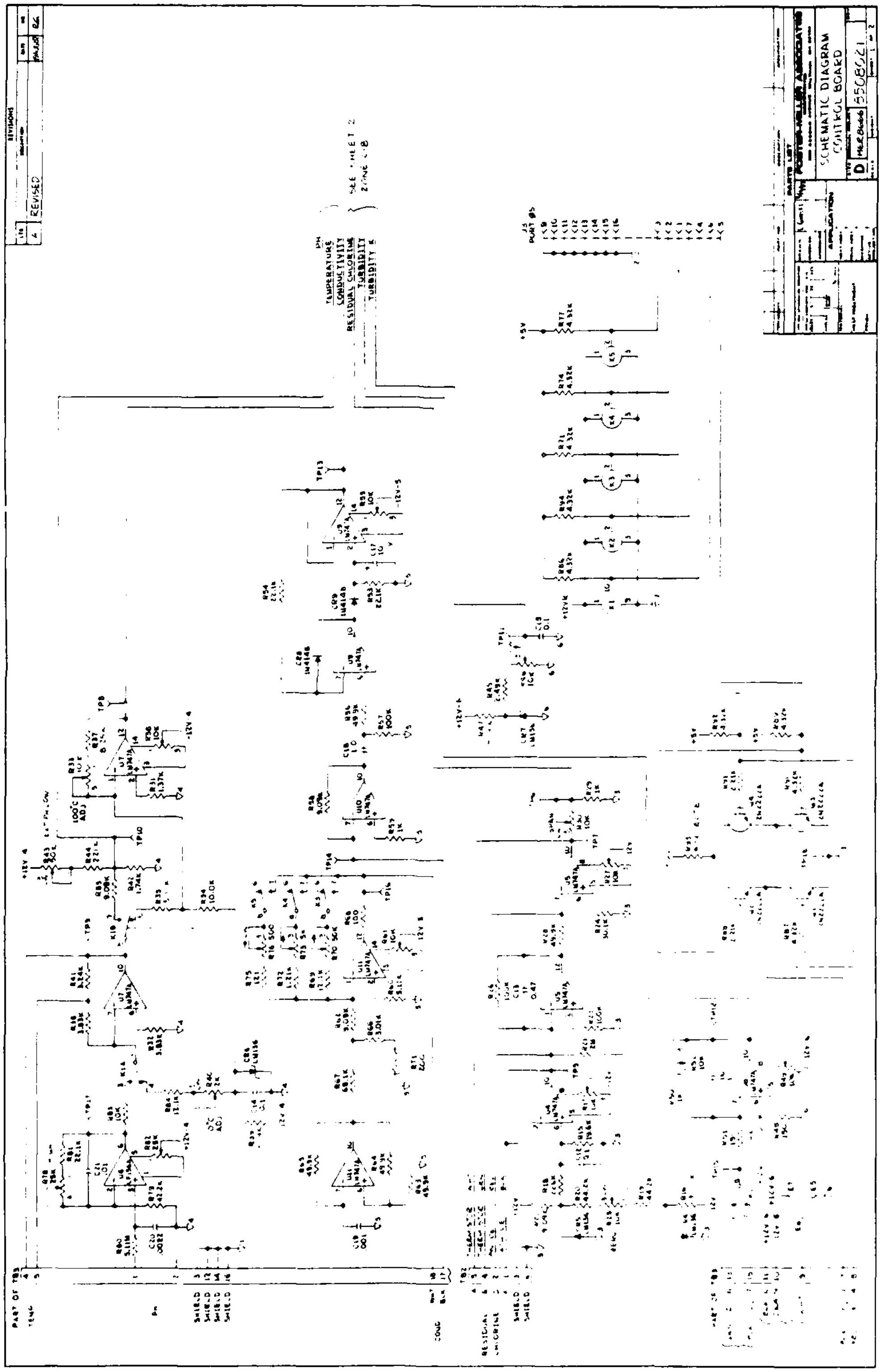

Figure 5-10. Schematic of Sensor Control Circuit Board

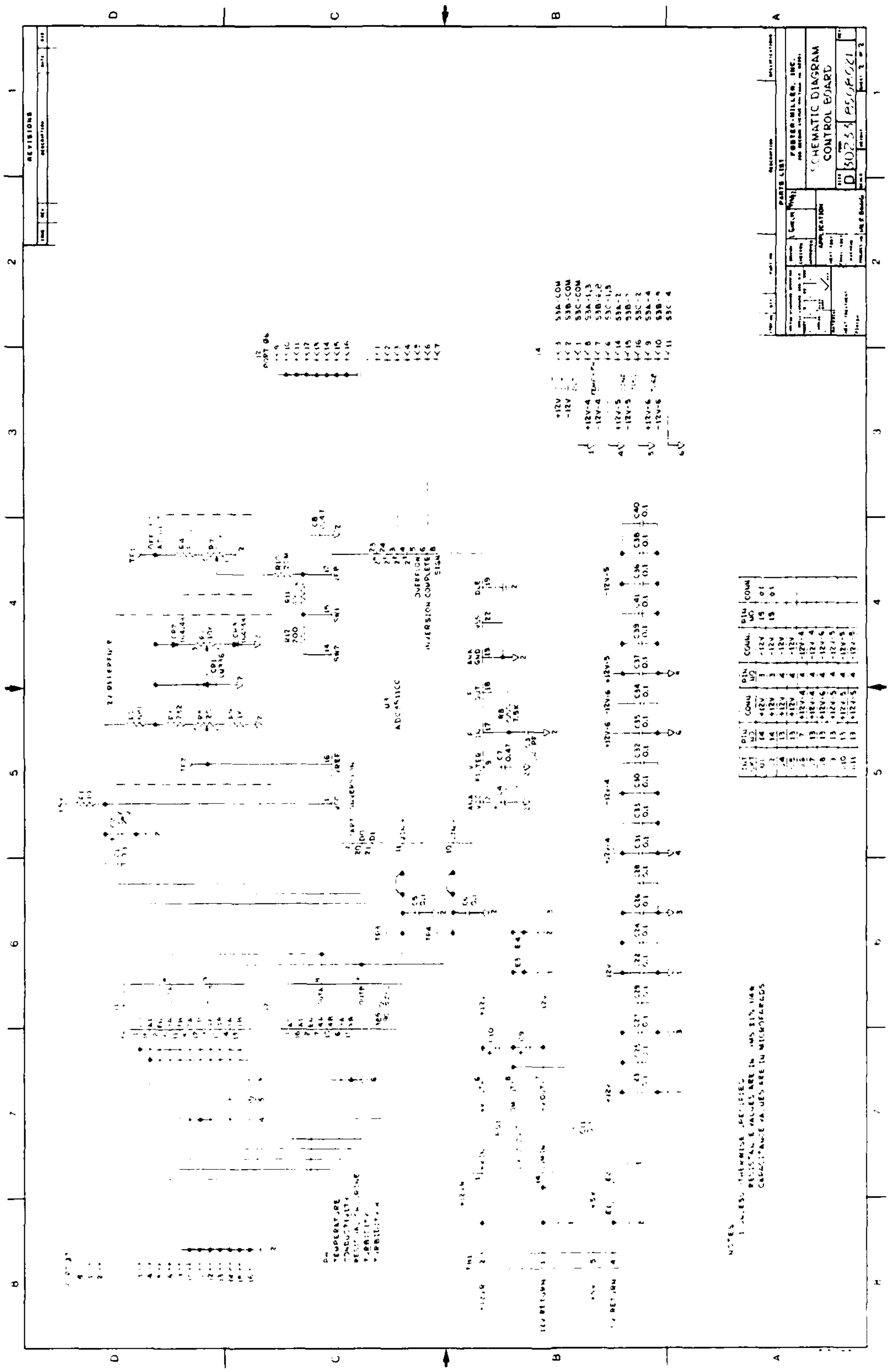

Figure 5-11. Schematic of Sensor Control Circuit Board

5.3.1.1 Temperature

The temperature measuring elements consists of two thermistors and a fixed resistor connected in a series-parallel combination that results in a resistance element that varies linearly as a function of temperature. This resistance element is placed in the feedback loop of an operational amplifier thereby causing the amplifier gain to be a function of temperature. A stable voltage is applied to this amplifier yielding an output voltage proportional to temperature. The output of this viable gain amplifier is fed into another amplifier whose gain is set to scale the output voltage for a 1 mV per 0.1^{o}C sensitivity. Two adjustments are provided for adjusting the 32^{o}F and 120^{o}F endpoints.

5.3.1.2 pH

The combination Ag/AgCl pH probe is connected to a high input impedance amplifier whose gain control is used to set the upper end of the pH slope. The output of this amplifier is connected by means of a relay that is activated by software control to the same amplifier stage used by the temperature probe. This provides the temperature compensation required by the pH probe. The output of the second stage is combined with an adjustable voltage source to set the low pH end point.

5.3.1.3 Conductivity (TDS)

The conductivity probe consists of two electrodes. An oscillating current is passed into the water sample through one of the two electrodes. The resulting current flow between the two electrodes, a function of water conductivity, is measured, manipulated by the microprocessor and displayed in TDS units. TDS levels are established by measuring the conductivity of the

water sample, correcting the conductivity reading for temperature effects and correlating the final result to equate to a specific salt (NaCl). The last two actions are handled by the microprocessor.

The WQAU-P provides three automatically selected (auto-ranging) measurement ranges: 0-500 mg/l, 500-5000 mg/l and 5000-50,000 mg/l. If the measurement is less than the lower value of the tested range, the microprocessor switches the TDS circuit to the next lower range. To accomplish this, the microprocessor switches component values which change the amplitude of the pulsed current. Separate non-interacting adjustments are provided for calibrating the current level injected into the water sample for each measurement range.

5.3.1.4 Turbidity

Turbidity measurements are attained by using a four beam light measurement technique that eleminates errors caused by dirty windows and variations in light level. The turbidity probe consists of two pairs of light emitting diodes (LED), photodetectors, amplifiers and narrow band optical filters. The absorption and scattering effects of suspended particles in the water sample is measured over for optical paths. The output of each LED is measured by each photodiode over fixed optical path lengths through the water sample. The four measurements are processed by the WQAU-P software to cancel out variations in the LED light sources, detectors and temperature. The resulting measurement of attenuated light is a function of water turbidity.

5.3.1.5 Chlorine

The chlorine sensor is an amperometric probe that has a gold cathode at its outer tip and an internal anode that is

made of silver. The body of the sensor is filled with a buffered KCl electrolyte. Channels within the Lody of the sensor transfer electrolyte from the reservoir to the gold cathode which is covered by a special permeable membrane. As the water being monitored flows past the sensor tip, hypochlorous acid molecules diffuse through the membrane and an electrical current is produced in proportion to the chlorine concentration of the sample.

5.3.2 Display Circuit Board (Figure 5-12)

The display circuit board contains a 5 digit, 0.3 in. high, green, seven segment display for indicating the results of the water quality measurement. The display is blanked after 15 sec to conserve battery power. The display circuit board is driven under software control. Leading zeroes are blanked to eliminate confusion and present concise readouts. Two ports on the I/O circuit board provide the input data and control signals to the display circuit board.

Connections to this circuit board are made by ribbon cables and connectors. The display board is mounted behind the control panel so that the displays can be viewed through a cutout on the panel. A green filter serves the dual purpose of enhancing the display by increasing contrast and serving as a watertight seal for the cutout.

5.3.3 I/O Circuit Board (Figure 5-13)

The CMOS STD BUS I/O Card manufactured by Pro-Log Corporation provides the interface between the STD BUS, the CPU circuit board and the outside world. Eight, eight-bit read/write ports control 64 bidirectional signal lines. The I/O ports are used to drive the display board, control the A/D converter, TDS autoranging and turbidity measurement

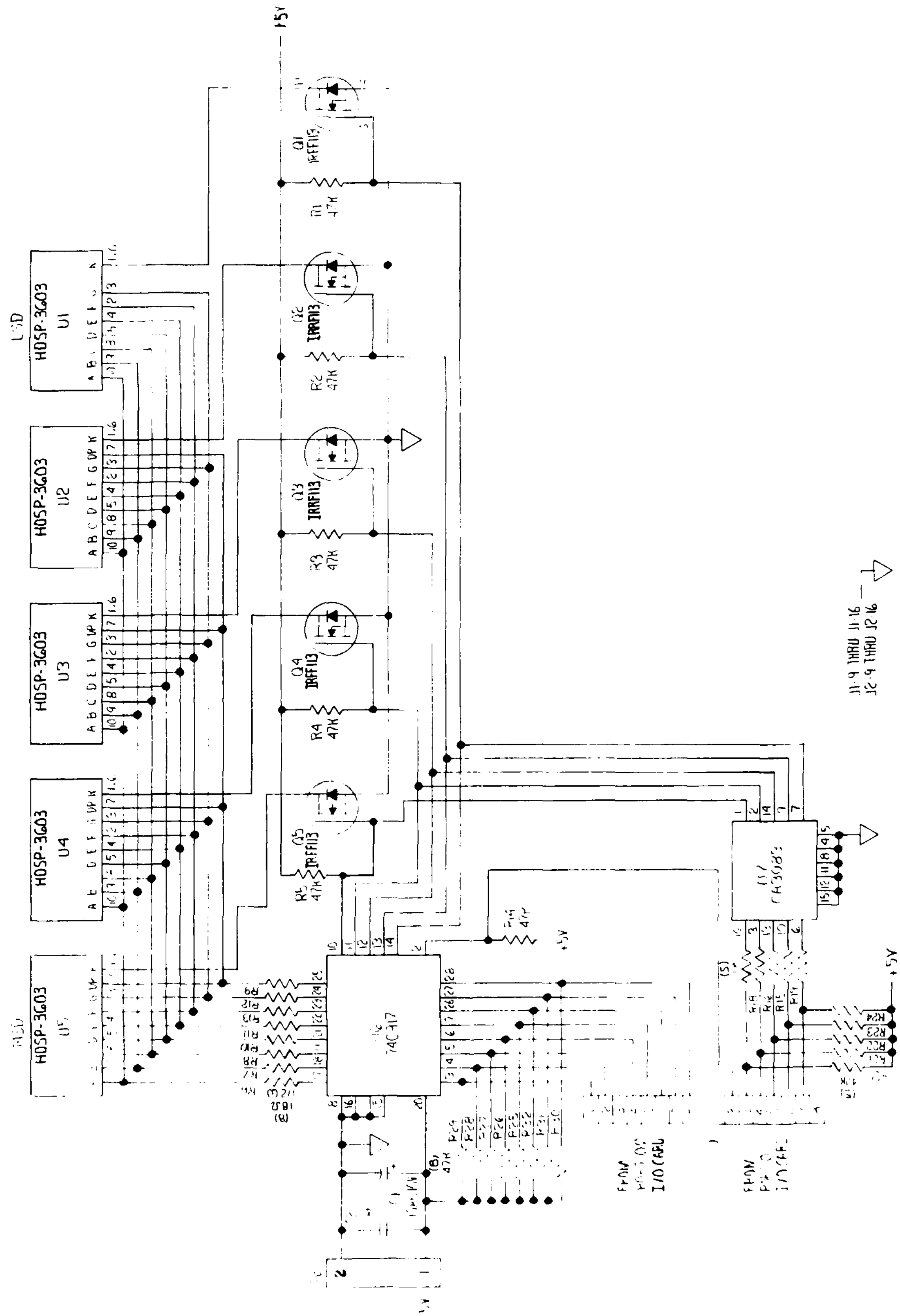

Figure 5-12. Schematic of Display Circuit Board

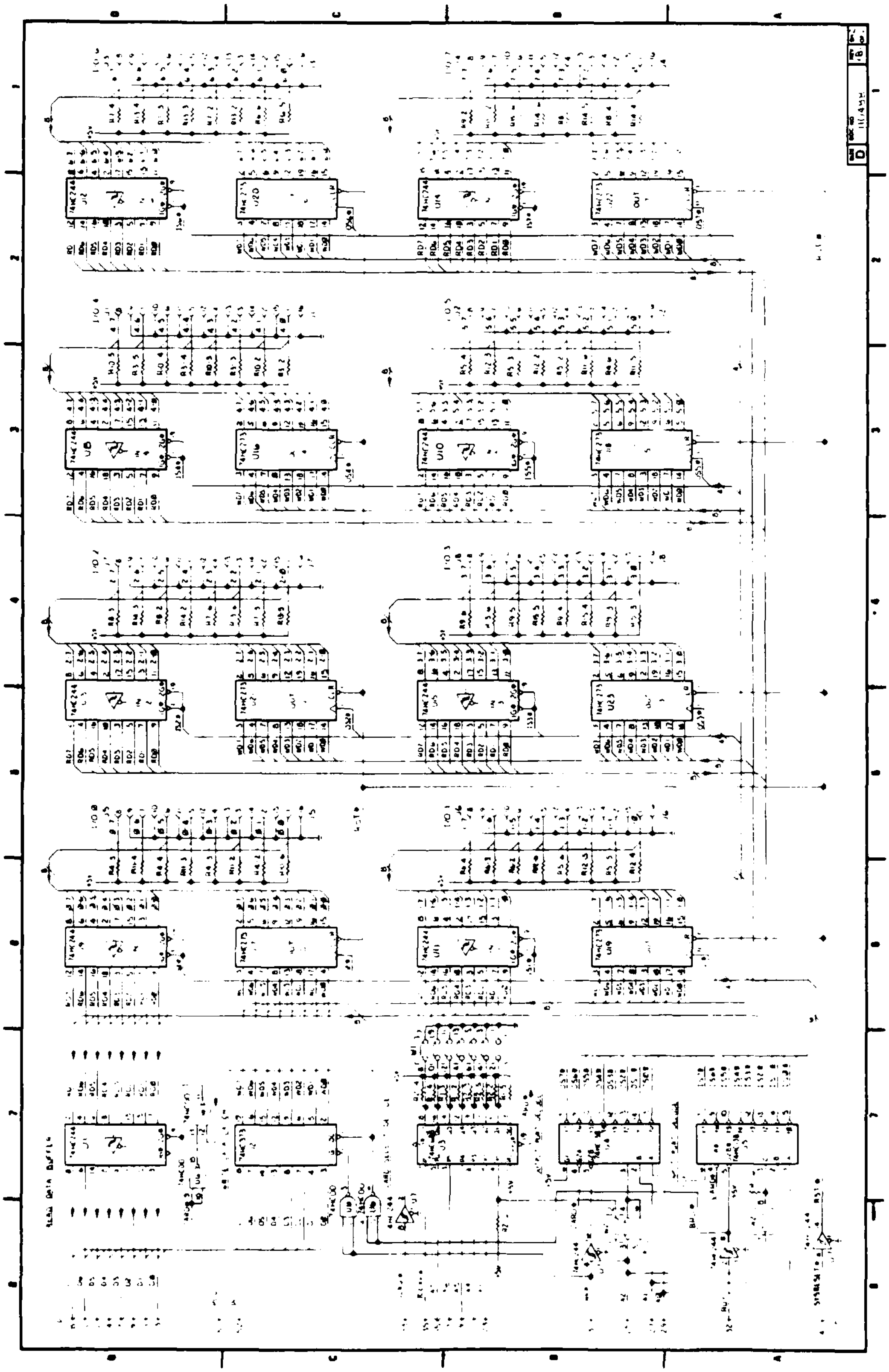

Figure 5-13. Schematic of Pro-Log I/O Circuit Board

sequences. The I/O board also signals the CPU as to which measurement to perform and what operating mode has been selected.

5.3.4 CPU Circuit Board (Figure 5-14)

The CMOS-CPU Card manufactured by Pro-Log Corporation is the microprocessor used in the WQAU-P. The microprocessor is a 80C85A which executes 8080/8085 software. The CPU board also contains sockets for EPRO memory which are not used due to limited on board memory. The WQAU-P software is programmed into 2 CMOS 8K x 8 27C64 Read Only Memory devices, located on the memory expansion board discussed in the next subsection. A 2K x 8 Random Access Memory device is used for temporary memory storage and stack operations. The CPU board also provides three direct restart interrupts. One interrupt is used by the Push to Read Switch to initiate a calibrate or measurement operation. CMOS type CPU, I/O and memory were chosen to minimize power requirements.

5.3.5 Memory Expansion Circuit Board (Figure 5-15 and 5-16)

The 77C08 CMOS 64K-byte Memory Board manufactured by Prolog Corporation is used by the WQAU-P to provide the space for the WQAU-P software contained in two 27C64 EPROMS. A memory expansion board was required because the WQAU-P software exceeded the memory capacity of the existing (GFE) CPU circuit board.

This memory board utilizes high speed CMOS that minimizes power requirements. The board has been configured by jumper selection so that memory is mapped from 0. All unused sockets and options such as segmentation and MEMEX have been disabled. Sockets U10 and U11 (MEM0, MEM1) contain the two EPROMS.

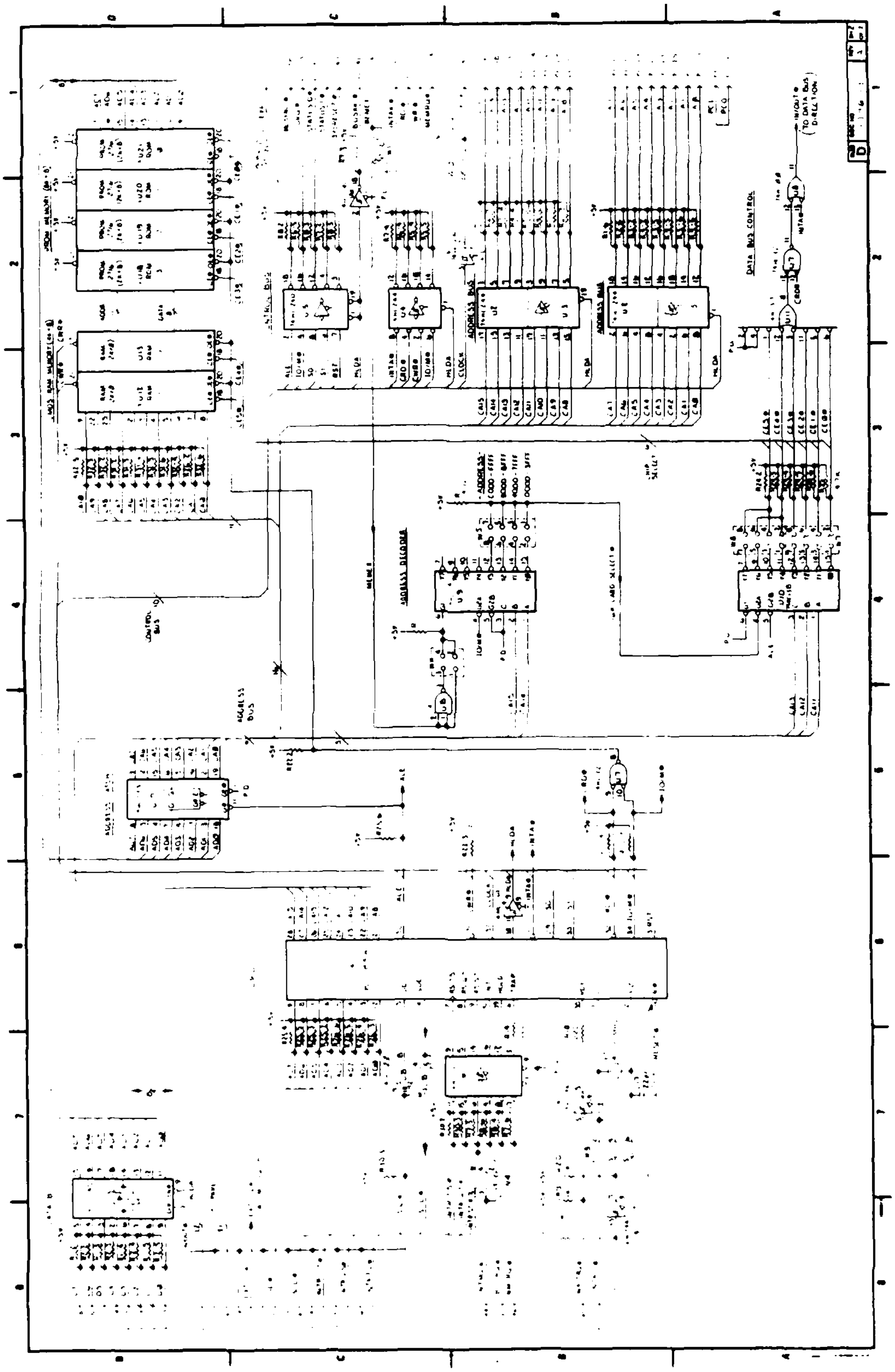

Figure 5-14. Schematic of Pro-Log CPU Circuit Board

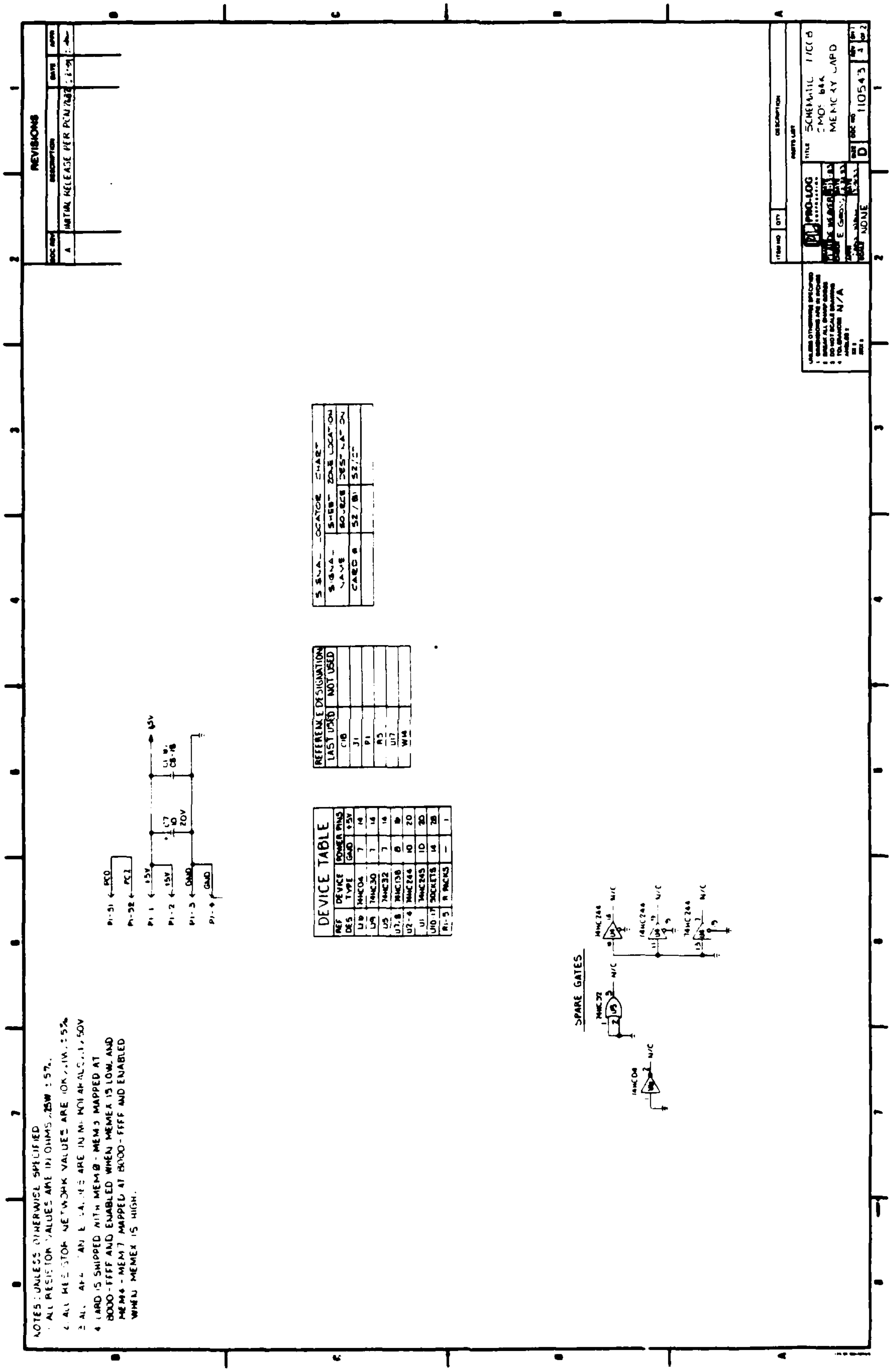

Figure 5-15. Schematic of Memory Expansion Circuit Board

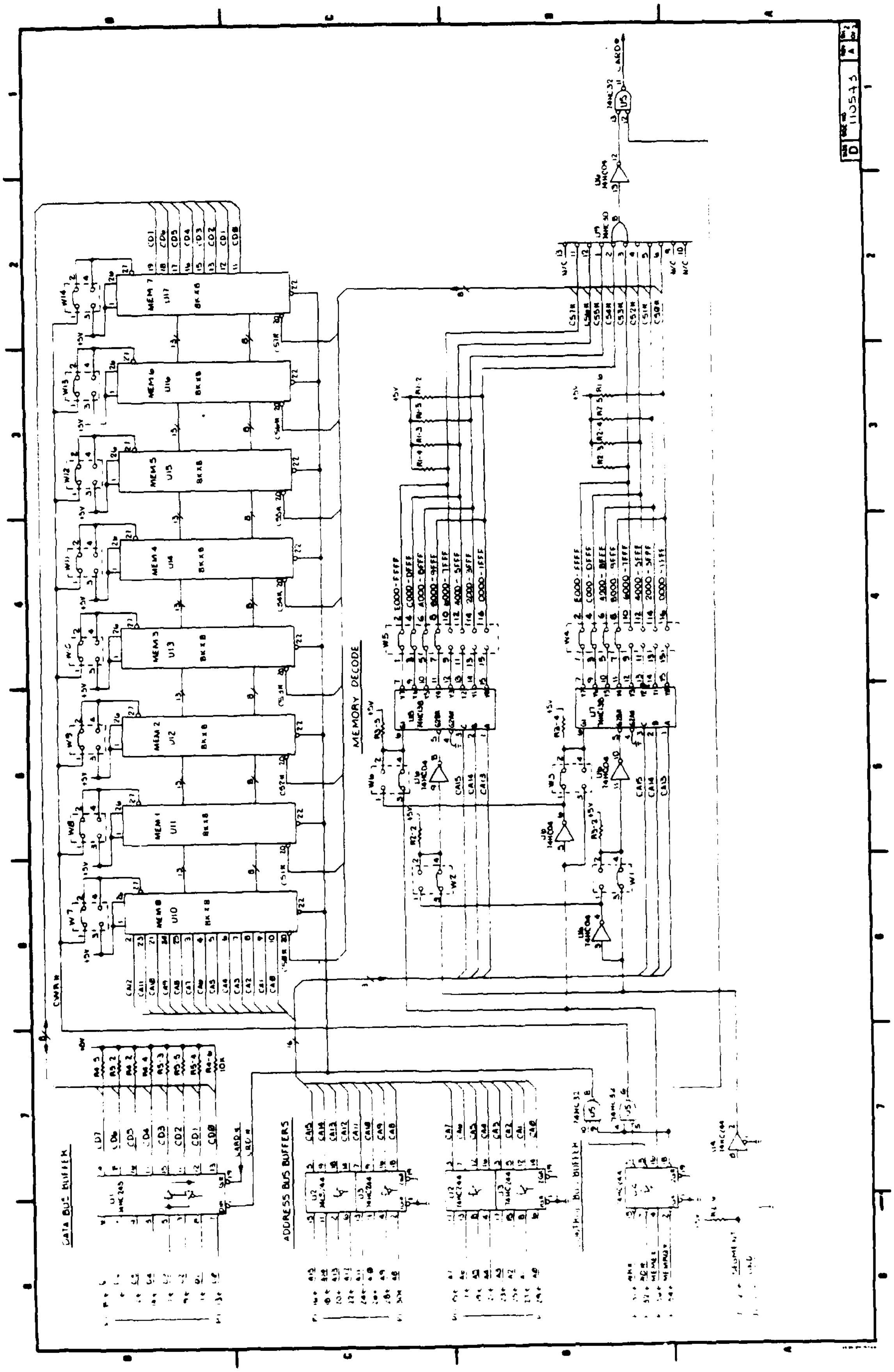

Figure 5-16. Schematic of Memory Expansion Circuit Board (Continued)

5.3.6 Power Supply Circuit Board (Figure 5-17)

The WQAU-P power supply provides power for the operating circuits from an internal battery or external power source. The external power source may be either 115 Vac, 230 Vac, 12 Vdc or 24 Vdc. A linear power supply operated from the power line provides a regulated +12 Vdc. This power supply provides separate primary transformer connections for either 115 Vac or 230 Vac operation. The +12 Vdc output voltage is used to provide trickle charging to the NICAD 12V battery, through a constant current charging circuit. Power is supplied to two dc/dc converters and one, three-terminal voltage regulator from either the +12 Vdc power supply, when operated from the powerline, or from the battery when the WQAU-P is not connected to the powerline.

A dc/dc converter, WF12805/1000Z manufactured by Power Products Inc., supplies +5 Vdc to the sensor control, CPU and I/O circuit boards. The residual chlorine circuitry is activated by the internal battery when the WQAU-P is turned off. When the WQAU-P is turned on, the residual chlorine circuits are powered from the +12 Vdc supply on the sensor control board to provide the floating power supply requirements of A/D converter. A low battery indicator is provided to indicate that the internal battery should be recharged.

5.4 Software

The software that performs the WQAU-P functions is written in 8080/8085 assembly language code and FORTRAN.

The assembly language code performs the WQAU-P control functions. These are measurement selection determination, calibrate/measure determination, TDS range determination, the push to read function, the turbidity measurement sequence and

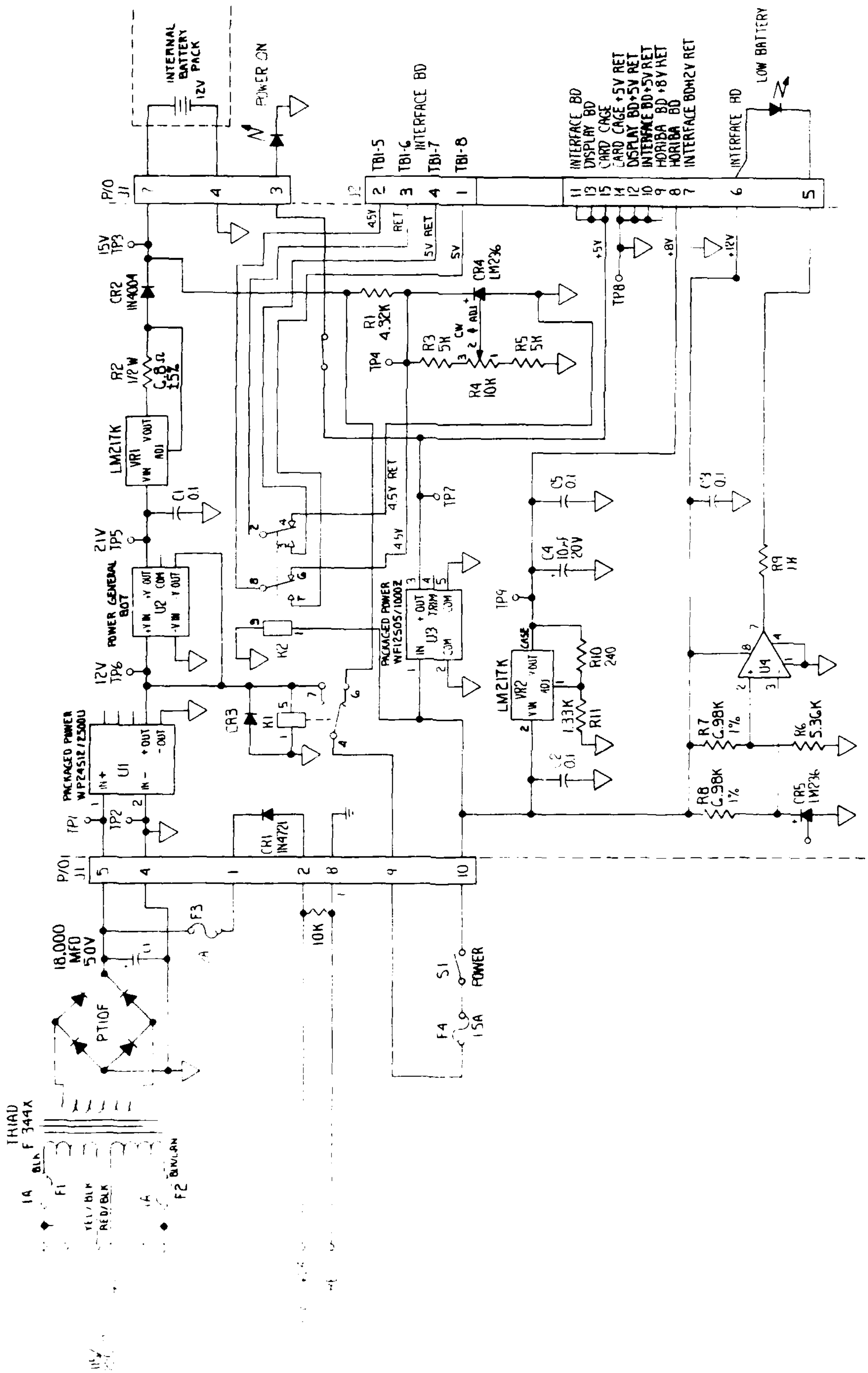

Figure 5-17. Schematic of Power Supply Circuit Board

the WQAU-P startup initiation. The assembly language subroutines also perform the data gathering and display control functions.

The FORTRAN subroutines do the numerical calculations for subtracting the offset, gathered during the calibrate mode, from the data obtained during the measure cycle. The FORTRAN subroutines perform the calculations that compensate the TDS readings for temperature effects, perform the turbidity calculations and compensate the residual chlorine readings for pH and temperature. The FORTRAN subroutines also manipulate the data passed to it from the assembly language code to be compatible with FORTRAN number formats and then again to be compatible with the display requirements. The data is passed to the FORTRAN code as four separate BCD digits that must be packed into one number for calculation purposes.

The resulting calculations must be unpacked into five separate BCD digits that are passed to the assembly language code for display. Leading zeroes are blanked.

The assembly language code and FORTRAN code subroutines are compiled into binary code which is stored in two CMOS EPROMS that reside on the memory expansion board.

A complete listing of the WQAU-P software is included in Appendix A.

5.5 Processing Algorithms

Turbidity, TDS and residual chlorine measurements utilize FORTRAN algorithms to process and manipulate sensor input data and to correct these readings for pH and/or temperature. Specifics of each algorithm are outlined in the following paragraphs.

5.5.1 Turbidity

The turbidity algorithm performs two distinct functions. The first function is performed independently of the WQAU-P mode of operation (i.e. calibrate or measure) and results in the generation of a calculated logarithmic value that is related to the suspended solids concentration of the water sample. The second function corrects the calculated logarithmic value generated during the measurement operation for shift in the zero (calibrate) turbidity reading and for changes in the water temperature from the calibration fluid temperature.

During the calibrate sequence the turbidity probe is placed in zero turbidity water. Each of the sensor's photodiode outputs (two) are initially measured while both of the sensor's LEDs are off. The output from each photodiode is then measured while the LEDs are individually turned on and off. The photodiode dark readings are then subtracted from the appropriate light induced photodiode readings. The resulting four measurements are manipulated to cancel the affects of LED intensity and photodiode sensitivity, and produce a logarithmic value that is proportional to water turbidity. This numerical procedure is detailed in subsection 4.2.3. The calculated logarithmic value and the temperature of the zero turbidity water sample are stored in the WQAU-P microprocessor for use in the measurement aglorithm.

During the measurement sequence the same type of individual sensor readings are obtained as described in the previous paragraph. The resulting calculated logarithmic value is then adjusted to compensate for temperature, to compensate for shift in zero turbidity calibration value and to convert into Nepholometric Turbidity Units (NTU). The algorithm which performs this corrective action is described by the following equation:

$$\text{Turbidity (NTU)} = \left\{ C_m - \left[C_o \cdot - \left[K_s \left(T_o - T_m \right) \right] \right] \right\} \Big/ K_t$$

where

C_m = logarithmic value of sensor output generated during measurement sequence

C_o = logarithmic value of sensor output generated during calibration sequence

K_s = Correction factor for shift in temperature

T_o = temperature of fluid used during calibration

T_m = temperature of water sample being measured

K_t = conversion factor for NTV output

5.5.2 TDS

The TDS probe selected for the multiparameter sensor measures the actual fluid conductivity in terms of millimhos per centrimeter. Since the conductivity of a salt solution varies considerably with temperature, the conductivity reading must be adjusted to a standard temperature and then converted to a concentration based on a particular salt. The WQAU-P TDS readings are expressed in terms of equivalent parts of NaCl.

Curves illustrating the temperature correlation between NaCl conductivity readings in micromhos per centimeter and salt concentration were obtained from Beckman Instruments.

Using these curves, an equation was developed which adjusts the conductivity readings to a standard temperature and converts the adjusted conductivity into a an equivalent NaCl concentration. This conversion equation is:

$$\text{NaCl (ppm)} = Z17754.8T^{-0.8354}\ K^{1.00398T^{0.01995}}$$

where

T = temperature in degrees Fahrenheit

K = conductivity in millimhos per centimeter

Z = temperature related correction factor

$T < 40^{o}F$	$Z = 0.0055\ (44-T) + 1$
$40 \leq T < 60$	$Z = 0.00005\ (T-60)^2 + 1$
$60 \leq T < 70$	$Z = 1.000$
$70 \leq T \leq 120$	$Z = 0.0024\ (T-70) + 1$

5.5.3 Free Available Chlorine

When elemental chlorine is dissolved in water two reactions take place:

Hydrolysis: $Cl_2 + H_2O \rightleftarrows HOCl + H^+ + Cl^-$

Ionization: $HOCl \rightleftarrows H^+ + OCl^-$

Hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) are referred to as the free available chlorine.

The sample pH, and to a lesser degree its temperature, controls the proportions of each of these chlorine species.

Figure 5-18 illustrates this relationship. Since the Xertex sensor measures only the hypochlorous acid a corrective factor must be used to adjust the sensor readings for changes in pH and temperature. Corrective factors are expressed as percentages and are divided into the sensor readings to provide the actual free available chlorine concentration. A correction table has been included in the microprocessor of the WQAU-P.

Figure 5-18 also illustrates that any free available chlorine determinations of water with a pH in excess of 9-9.5 will be relatively meaningless. This should present little if any difficulties since the product water from the RO system is rarely if ever above a pH of 9. In fact, input waters to the RO system with a pH above 9 will degrade or destroy the RO membranes.

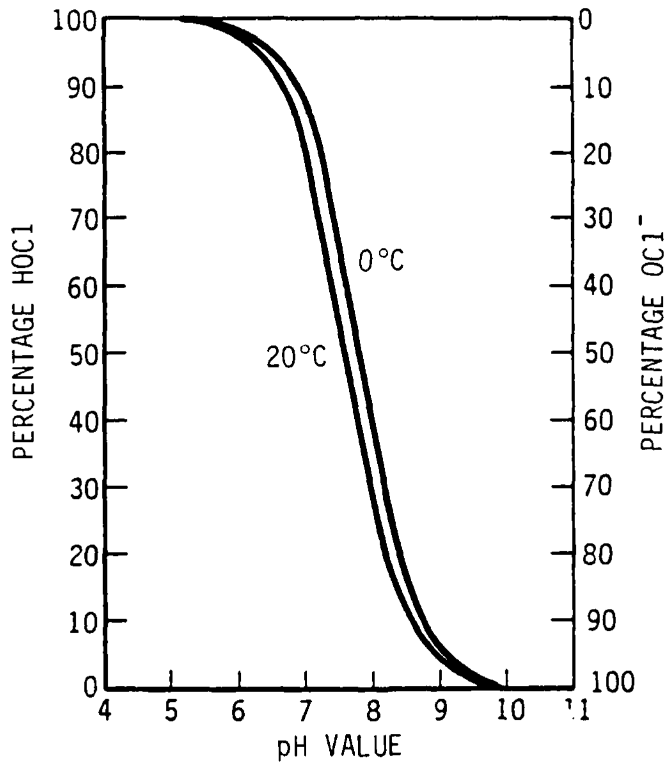

Figure 5-18. Distribution of Hypochlorous Acid and Hypochlorite Ion in Water at Different pH Values and Temperatures

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6. WQAU-P OPERATIONS

WQAU-P operations have been divided into six basic categories. They are:

- Preparation for use
- Field calibration
- Measurement
- Field maintenance
- Laboratory calibration
- Laboratory maintenance.

Preparation for use covers the basic operations needed to ensure that the WQAU-P is totally functional and that all required components and accessories are assembled prior to placing the WQAU-P into field use.

Field calibration operations are performed by the user in the field. This is a very simple procedure which makes adjustments for electrical shifts in the zero or standardized readings of each parameter.

Measurement operations describe the procedures for obtaining instrument readings.

Field Maintenance operations are general procedures that can be performed by the user in the field. This would include cleaning sensor heads, replacing electrolytic fluids and replacing certain sensors.

Laboratory calibration operations must be performed by a qualified laboratory technician. This level of calibration sets the zero value and span value for each parameter.

Laboratory maintenance operations must be performed by a qualified laboratory technician. This would include replacing electrical boards and/or sensors.

Details are available in the commercial grade manual prepared in accordance with CDRL A0005 and titled "Operating and Service Instructions for Water Quality Analysis Unit-Purification" March 1987.

7. RESULTS OF WQAU-P VALIDATION TESTING

Six WQAU-Ps with individual multiparameter sensors were subjected to an extended matrix of tests. This test matrix is detailed in Table 7-1.

Table 7-1. Parametric Test Matrix

Parameter	Measurement Level	Fluid Operating Range	Measure-ments	Measure-ments per Sample	Total Measure-ments
pH	4, 7, 10 pH units	$36^{\circ}F$, $68^{\circ}F$, $100^{\circ}F$, $120^{\circ}F$	12	10	120
TDS	50, 100, 500, 1,500, 3,000, 30,000, 50,000 mg/l	$36^{\circ}F$, $68^{\circ}F$, $100^{\circ}F$, $120^{\circ}F$	28	10	280
Turbidity	3, 10, 50, 100, 150 NTU	$36^{\circ}F$, $68^{\circ}F$, $100^{\circ}F$, $120^{\circ}F$	20	10	200
Residual Chlorine	1, 7, 15	$36^{\circ}F$, $68^{\circ}F$, $90^{\circ}F$ and 5.5, 7.5 pH units	18	10	180
Temperature (Air)	$10^{\circ}F$, $20^{\circ}F$, $140^{\circ}F$, $160^{\circ}F$	N/A	4	10	40

More than 5,400 individual measurements were taken/recorded with the Phase III WQAU-P/multiparameter sensors. Over 95 percent of the readings fell within the accuracy requirements for the parametric measurements. The multiparameter sensor provided over a 97 percent accuracy rate. Residual chlorine was less impressive, logging an 89 percent accuracy rate.

The cumulative percentage of correct readings for each parameter is listed in Table 7-2.

Table 7-2. Cumulative Test Results

Parameter	Total Number of Tests	Percent Correct Readings
Temperature (Fluid)	493	97
Extreme Temperature (Air)	240	85
Total Dissolved Solids	1,680	98
pH	720	100
Turbidity	1,200	95
Residual Chlorine	1,080	89

On an individual WQAU-P basis, the percentage of correct parametric measurements ranged as follows:

- Temperature (fluid) - 94 to 99 percent
- Extreme temperature (air) - 60 to 98 percent
- Total dissolved solids - 93 to 100 percent
- pH - 100 percent (no failures)
- Turbidity - 89 to 99 percent
- Residual chlorine - 78 to 97 percent.

Individual WQAU-P results are summarized in Table 7-3.

Over 55 percent of the TDS errors occurred when measuring salt concentrations of 50,000 mg/l (upper level of measurement). Turbidity errors were evenly distributed over all ranges. Approximately 60 percent of the residual chlorine errors occurred at the upper limit of 15 mg/l. Approximately 75 percent of the temperatures errors occurred below $40^{\circ}F$ when measuring fluids between 32° and $120^{\circ}F$. At extreme temperatures (10° to $20^{\circ}F$ and 140° to $160^{\circ}F$), 95 percent of the errors occurred at the high range.

Details of test procedures, test results and data analysis are available in the demonstration and test report prepared in accordance with CDRL A013 and titled "Demonstration and Test Report of the WQAU-P Validation Testing" June 1987.

Table 7-3. Test Results for Individual WQAU-Ps

WQAU-P/Multiparameter Sensor	1/1	3/8	6/5	7/4	5/3	4/6
Parameter	Percent Correct Readings					
Temperature (Fluid)	94	99	96	96	98	99
Extreme Temperature (Air)	98	75	85	95	60	98
Total Dissolved Solids	100	98	98	93	100	100
pH	100	100	100	100	100	100
Turbidity	99	99	98	89	97	90
Residual Chlorine	78	85	93	92	97	88

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8. CONCLUSIONS

The Phase II WQAU-P developed during 1985-1986 was retrofitted to include a newly developed multiparameter sensor and modified mechanically to improve the unit's ability to survive rough handling and harsh environments. This improved Phase III WQAU-P occupies 2.0 ft^3 and weighs 46 lb. The WQAU-P's simplified calibration and measurement routines can be easily completed in less than 5 min. Only one liquid standard (a mixture of DI water and a sealed packet of pH buffer powder) is required for field calibration. Trained personnel, experienced with the WQAU-P's operation, have performed a complete calibration and measurement sequence in less than 3 min.

All conclusions are based on Foster-Miller's direct experience with the fabrication, assembly, validation testing and field service of the WQAU-Ps.

- The revised WQAU-P with the newly developed multiparameter sensor was able to meet the parametric accuracy requirements for temperature, pH, TDS and turbidity on an average of 97 percent

- Residual chlorine measurements were less impressive, logging only an 89 percent accuracy rate

- The modified WQAU-P case with the improved EMP gasket successfully passed the EMP testing at White Sands

- EMI, drop, decontamination and shock testing by the Government was not completed as of the writing of this Final Report

- The electrical connector for the temperature probe and the TDS probe should be changed to provide easier assembly and a watertight connection at the electrical end

- The spanner nut/gasket design for the three replaceable multiparameter probes did not provide a quality seal against water leakage into the probe socket

- Dead space inside the TDS probe above the sensing elements provides a fluid trap that can contaminate future water samples and produce slightly inaccurate results

- The pH probe requires further protection to minimize breakage due to rough handling

- Residual chlorine measurement techniques/sensor needs to be improved.

9. RECOMMENDATIONS

Recommendations generated from the outcome of this program are directed at two specific goals.

- Improving the WQAU-P's accuracy/repeatability, survivability and maintainability

- Reducing the WQAU-P's size and weight.

The recommendations for reducing the WQAU-P's size/weight are detailed in our weight reduction feasibility report prepared in accordance with CDRL A0009 and titled "Feasibility Study for WQAU-P Weight Reduction." The recommendations listed below are directed at improving the WQAU-P's accuracy, survivability and maintainability.

- Conduct a state-of-the-art survey to see if any new or innovative residual chlorine measurement techniques have been developed since the conception of this program

- Determine if the existing chlorine sensor or measurement technique can be improved to provide more repeatability measurements

- Design a protective cage that will protect the glass bulb of the pH electrode from breakage

- Eliminate the dead space in the TDS probe by filling this void with epoxy

- Continue testing the Phase III WQAU-P to determine the unit's ability to meet EMI, transit drop, decontamination and shock requirements

- Replace the pin type connectors of the temperature probe and TDS probe with coaxial and triaxial connectors, respectively

- The spanner nut used to secure the probes into the multiparameter sensor assembly should be changed into a hex nut design

- Redesign the probe gasket and seating arrangement associated with the spanner nut.

APPENDIX A
WQAU-P Software

```
ASM80 :F1:NTRY.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1        NTRY1    PAGE    1


 LOC  OBJ          LINE        SOURCE STATEMENT

                         ;             WQM3

                                NAME    NTRY1            ;2/16/87



                         ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                EXTRN   EOD,TYPBR,BLNKAL
                                PUBLIC  D1,D2,D3,D4,D5,DELAY,LDLY

                         ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;


                                                DSEG

 0000                           FLASH:  DS      1               ;STRG FOR PARAM PASS FROM FORTRAN
 0001                           D1:     DS      1               ;LSB DISPLAY
 0002                           D2:     DS      1               ;LSB+1 DISPLAY
 0003                           D3:     DS      1               ;LSB+2 DISPLAY
 0004                           D4:     DS      1               ;LSB+3 DISPLAY
 0005                           D5:     DS      1               ;MSB DISPLAY


                         ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                                ASEG

 0000                                           ORG     0H

 0000 31F0E7                    BEGIN:  LXI     SP,0E7F0H       ;SET STACK POINTER
 0003 3EFF                              MVI     A,0FFH
 0005 D301                              OUT     01H             ;BLANK DISPLAY
 0007 3E1E                              MVI     A,1EH           ;BIT PATTERN FOR INTERRUPT MASK
 0009 30                                SIM                     ;SET INTRPT MASK


 000A 0608                      DSP8:   MVI     B,08H           ;SET TO DISPLAY 88888
 000C CD0000     E                      CALL    EOD
 000F C30000     E                      JMP     BLNKAL

 0012 2173CB                    DELAY:  LXI     H,0CB73H        ;.5 SEC. DELAY CONSTANT
 0015 2B                        DLY:    DCX     H               ;DECREMENT LOOP CTR
 0016 7C                                MOV     A,H             ;GET READY FOR H=L=0=LOOP DONE
 0017 B5                                ORA     L               ;H & L=0(COUNTER ZERO)
 0018 C21500                            JNZ     DLY             ;COUNTER NOT =0( ( .5 SEC. )
 001B C9                                RET


 001C CD1200                    LDLY:   CALL    DELAY           ;LONG DELAY CONSTANT IN B
 001F 05                                DCR     B
 0020 C21C00                            JNZ     LDLY            ;LOOP SOME MORE
 0023 C9                                RET                     ;BACK

```

```
 LOC  OBJ         LINE        SOURCE STATEMENT

 0024 00           55               NOP
 0025 00           56               NOP                     ;FILLER TO 5.5 INTERRUPT LOC.
 0026 00           57               NOP
 0027 00           58               NOP
 0028 00           59               NOP
 0029 00           60               NOP
 002A 00           61               NOP
 002B 00           62               NOP
                   63
 002C C30000   E   64         DOITV: JMP    TYPBR           ;GO TO /CAL MEAS & TYPE SUBROUTINE
                   65               END

ASSEMBLY COMPLETE,   NO ERRORS
```

```
ASM80 :F1:TYP.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1        TYP01    PAGE    1


 LOC  OBJ         LINE        SOURCE STATEMENT

                           ;                  WQM3

                           ;                         PORT 02

                           ;                       7 6 5 4 3 2 1 0
                           ;                       - - - - - - - 0 TEMP
                           ;                       - - - - - - 0 - TDS
                           ;                       - - - - - 0 - - PH
                           ;                       - - - - 0 - - - TURB
                           ;                       - - - 0 - - - - RCHL
                           ;                       - - X - - - - - /CAL-MEAS

                                 NAME    TYP01                  ;2/16/87


                           ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;


                                 EXTRN   PHOF,PHM,TEMPER,RCLOFS,RCLM,TDSOF,TDSMB,TURBOF,TURBM

                                 PUBLIC  TYPBR

                           ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;



                                                CSEG


0000 31F0E7                      TYPBR:  LXI    SP,0E7F0H      ;RESET STACK POINTER

0003 3EFF                                MVI    A,0FFH         ;BLANK DISPLAY
0005 D301                                OUT    01
0007 DB02                                IN     02H            ;GET TYPE BITS
0009 E63F                                ANI    3FH            ;CAL/MEAS/& TYPE
000B FE1B                                CPI    1BH            ;(CAL) . (PH) ?
000D CA0000      E                       JZ     PHOF           ;YES CALCULATE OFFSET
0010 FE3B                                CPI    3BH            ;(MEAS) . (PH)?
0012 CA0000      E                       JZ     PHM            ;MEASURE PH


0015 FE1E                                CPI    1EH            ;(CAL) . (TEMP)?
0017 CA0000      E                       JZ     TEMPER         ;SETS ITEMP=N
001A FE3E                                CPI    3EH            ;(MEAS) . (TEMP)
001C CA0000      E                       JZ     TEMPER


001F FE0F                                CPI    0FH            ;(CAL) . (RESID CHLORINE)?
0021 CA0000      E                       JZ     RCLOFS         ;OFFSET FOR R CL
0024 FE2F                                CPI    2FH            ;(MEAS) . (R CL)?
0026 CA0000      E                       JZ     RCLM           ;MEASURE R CL
```

```
 LOC  OBJ           LINE        SOURCE STATEMENT

 0029 FE1D            55                 CPI     1DH            ;(CAL) . (CONDUCTIVITY)
 002B CA0000   E      56                 JZ      TDSOF          ;GET COND OFFSET
 002E FE3D            57                 CPI     3DH            ;MEAS AND COND?
 0030 CA0000   E      58                 JZ      TDSMB          ;MEASURE COND FOR TDS
                      59
                      60
 0033 FE17            61                 CPI     17H            ;(CAL) . (TURBIDITY)?
 0035 CA0000   E      62                 JZ      TURBOF         ;GET TURB OFFSET
 0038 FE37            63                 CPI     37H            ;MEASURE TURBIDITY
 003A CA0000   E      64                 JZ      TURBM          ;MEASURE IT
                      65
                      66
                      67
                      68
                      69                 END

ASSEMBLY COMPLETE,    NO ERRORS
```

```
ASM80 :F1:CAL.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1        CAL1     PAGE    1


 LOC  OBJ         LINE        SOURCE STATEMENT

                        ;              WQM3

                                NAME    CAL1            ;2/17/87

                        ;DESCRIPTION: MACRO USED TO PERFORM CALIBRATIONS AND MEASUREMENTS
                        ;             VARIABLES ARE MEASUREMENT SETTLING TIME CONSTANTS,
                        ;             (G1),CALIBRATION NAME SUBROUTINES, OR MEASUREMENT
                        ;             NAME SUBROUTINES (G2).
                        ;               (G3) IS THE DECIMAL POINT FLAG
                        ;               (G4) IS PORT 07 BIT SETTINGS
                        ;               (G5) IS PORT 05 BIT SETTINGS (RELAY CONTROL)

                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                EXTRN   LDLY,RDSENS,PACK,UNPACK,DISPLA,BLNKAL,ERTRAP
                                EXTRN   PHOFS,RCLO,OFFST
                                EXTRN   FQ0GO
                                EXTRN   D2

                                PUBLIC  PHOF,RCLOFS

                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;


                                MCM     MACRO   G1,G2,G3,G4,G5

 -                                      MVI     A,G5            ;SET PORT 05 TO CONTROL RELAYS
 -                                      OUT     05H             ;SET PORT
 -                                      MVI     A,G4            ;SET PORT 07 FOR MUX CHANNEL
 -                                      OUT     07H             ;OUTPUT IT
 -                                      MVI     B,G1            ;SETTLING TIME CONSTANT
 -                                      CALL    LDLY            ;WAIT FOR RDG TO SETTLE
 -                                      CALL    RDSENS          ;GET BCD DIGITS FROM HORIBA
 -                                      CALL    ERTRAP          ;ELIMINATE STRAY OUT OF RNGE RDG
 -                                      CALL    G2              ;SUBTRACT OFFSET OR ----
 -                                      CALL    UNPACK          ;UNPACK RESULT FOR DISPLAY
 -                                      CALL    OFFST           ;CHECK FOR EXCESSIVE OFFSET 50MV
 -                                      LDA     D2              ;SECOND DIGIT HAS DECIMAL POINT
 -                                      ORI     G3              ;0H=NO DEC. POINT--10H=DEC. POINT
 -                                      STA     D2              ;SAVE DATA
 -                                      CALL    DISPLA          ;PUT UNPACKED DIGITS IN DSP REG
 -                                      JMP     BLNKAL          ;BLANK ALL DIGITS
 -
                                        ENDM


                                                CSEG

  0000 CD0000   E                       CALL    FQ0GO           ;INITIALIZE FORTRAN I/O

                                PHOF:   MCM     05H,PHOFS,10H,58H,08H   ;2.5SEC,PH OFFSET,D.P.,P 07
                          +
  0003 3E08               +             MVI     A,08H           ;SET PORT 05 TO CONTROL RELAYS
```

```
 LOC  OBJ        LINE      SOURCE STATEMENT

 0009 D307                         OUT    07H              ;OUTPUT IT
 000B 0605                         MVI    B,05H            ;SETTLING TIME CONSTANT
 000D CD0000   E                   CALL   LDLY             ;WAIT FOR RDG TO SETTLE
 0010 CD0000   E                   CALL   RDSENS           ;GET BCD DIGITS FROM HORIBA
 0013 CD0000   E                   CALL   ERTRAP           ;ELIMINATE STRAY OUT OF RNGE RDG
 0016 CD0000   E                   CALL   TEMPS            ;SUBTRACT OFFSET OR ----
 0019 CD0000   E                   CALL   UNPACK           ;UNPACK RESULT FOR DISPLAY
 001C 3A0000   E                   LDA    D2               ;SECOND DIGIT HAS DECIMAL POINT
 001F F610                         ORI    10H              ;0H=NO DEC. POINT--10H=DEC. POINT
 0021 320000   E                   STA    D2               ;SAVE DATA
 0024 CD0000   E                   CALL   DISPLA           ;PUT UNPACKED DIGITS IN DSP REG
 0027 C30000   E                   JMP    BLNKAL           ;BLANK ALL DIGITS
                          PHM:     MCM    05H,PHMC,10H,058H,08H   ;2.5SEC,PH MEAS,D.P.,P 06
 002A 3E08                         MVI    A,08H            ;SET PORT 05 FOR RELAY ENABLE
 002C D305                         OUT    05H              ;SET PORT
 002E 3E58                         MVI    A,058H           ;SET PORT 06 FOR MUX CHANNEL
 0030 D307                         OUT    07H              ;OUTPUT IT
 0032 0605                         MVI    B,05H            ;SETTLING TIME CONSTANT
 0034 CD0000   E                   CALL   LDLY             ;WAIT FOR RDG TO SETTLE
 0037 CD0000   E                   CALL   RDSENS           ;GET BCD DIGITS FROM HORIBA
 003A CD0000   E                   CALL   ERTRAP           ;ELIMINATE STRAY OUT OF RNGE RDG
 003D CD0000   E                   CALL   PHMC             ;SUBTRACT OFFSET OR ----
 0040 CD0000   E                   CALL   UNPACK           ;UNPACK RESULT FOR DISPLAY
 0043 3A0000   E                   LDA    D2               ;SECOND DIGIT HAS DECIMAL POINT
 0046 F610                         ORI    10H              ;0H=NO DEC. POINT--10H=DEC. POINT
 0048 320000   E                   STA    D2               ;SAVE DATA
 004B CD0000   E                   CALL   DISPLA           ;PUT UNPACKED DIGITS IN DSP REG
 004E C30000   E                   JMP    BLNKAL           ;BLANK ALL DIGITS
                          RCLM:    MCM    05H,RCLMC,10H,50H,0H    ;2.5SEC,R CHL MEAS,D.P.,P 06
 0051 3E00                         MVI    A,0H             ;SET PORT 05 FOR RELAY ENABLE
 0053 D305                         OUT    05H              ;SET PORT
 0055 3E50                         MVI    A,50H            ;SET PORT 06 FOR MUX CHANNEL
 0057 D307                         OUT    07H              ;OUTPUT IT
 0059 0605                         MVI    B,05H            ;SETTLING TIME CONSTANT
 005B CD0000   E                   CALL   LDLY             ;WAIT FOR RDG TO SETTLE
 005E CD0000   E                   CALL   RDSENS           ;GET BCD DIGITS FROM HORIBA
 0061 CD0000   E                   CALL   ERTRAP           ;ELIMINATE STRAY OUT OF RNGE RDG
 0064 CD0000   E                   CALL   RCLMC            ;SUBTRACT OFFSET OR ----
 0067 CD0000   E                   CALL   UNPACK           ;UNPACK RESULT FOR DISPLAY
 006A 3A0000   E                   LDA    D2               ;SECOND DIGIT HAS DECIMAL POINT
 006D F610                         ORI    10H              ;0H=NO DEC. POINT--10H=DEC. POINT
 006F 320000   E                   STA    D2               ;SAVE DATA
 0072 CD0000   E                   CALL   DISPLA           ;PUT UNPACKED DIGITS IN DSP REG
 0075 C30000   E                   JMP    BLNKAL           ;BLANK ALL DIGITS
                                   END

ASSEMBLY COMPLETE,    NO ERRORS
```

```
ASM80 :F1:MES.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS

ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1        MES1     PAGE    1


  LOC  OBJ         LINE        SOURCE STATEMENT

                      1 ;              WQM3
                      2
                      3        NAME    MES1            ;2/17/87
                      4
                      5 ;DESCRIPTION: MACRO USED TO PERFORM CALIBRATIONS AND MEASUREMENTS
                      6 ;             VARIABLES ARE MEASUREMENT SETTLING TIME CONSTANTS,
                      7 ;             (G1),CALIBRATION NAME SUBROUTINES, OR MEASUREMENT
                      8 ;             NAME SUBROUTINES (G2).
                      9 ;               (G3) IS THE DECIMAL POINT FLAG
                     10 ;               (G4) IS PORT 07 BIT SETTINGS
                     11
                     12 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                     13
                     14        EXTRN   LDLY,RDSENS,PACK,UNPACK,DISPLA,BLNKAL,ERTRAP
                     15        EXTRN   PHOFS,TEMPS,RCLO,PHMC,RCLMC
                     16        EXTRN   FQ0GO
                     17        EXTRN   D2
                     18
                     19        PUBLIC  TEMPER,PHM,RCLM
                     20
                     21 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                     22
                     23
                     24        MCM     MACRO   G1,G2,G3,G4,G5
                     25
 -                   26                MVI     A,G5            ;SET PORT 05 FOR RELAY ENABLE
 -                   27                OUT     05H             ;SET PORT
 -                   28                MVI     A,G4            ;SET PORT 06 FOR MUX CHANNEL
 -                   29                OUT     07H             ;OUTPUT IT
 -                   30                MVI     B,G1            ;SETTLING TIME CONSTANT
 -                   31                CALL    LDLY            ;WAIT FOR RDG TO SETTLE
 -                   32                CALL    RDSENS          ;GET BCD DIGITS FROM HORIBA
 -                   33                CALL    ERTRAP          ;ELIMINATE STRAY OUT OF RNGE RDG
 -                   34                CALL    G2              ;SUBTRACT OFFSET OR ---
 -                   35                CALL    UNPACK          ;UNPACK RESULT FOR DISPLAY
 -                   36                LDA     D2              ;SECOND DIGIT HAS DECIMAL POINT
 -                   37                ORI     G3              ;0H=NO DEC. POINT--10H=DEC. POINT
 -                   38                STA     D2              ;SAVE DATA
 -                   39                CALL    DISPLA          ;PUT UNPACKED DIGITS IN DSP REG
 -                   40                JMP     BLNKAL          ;BLANK ALL DIGITS
 -                   41
                     42                ENDM
                     43
                     44
                     45                        CSEG
                     46
  0000 CD0000   E    47                CALL    FQ0GO           ;INITIALIZE FORTRAN I/O
                     48
                     49
                     50        TEMPER: MCM     05H,TEMPS,10H,54H,0H    ;2.5SEC,TEMP OFF & MEAS,P 06
                     51+
  0003 3E00          52+               MVI     A,0H            ;SET PORT 05 FOR RELAY ENABLE
  0005 D305          53+               OUT     05H             ;SET PORT
  0007 3E54          54+               MVI     A,54H           ;SET PORT 06 FOR MUX CHANNEL
```

```
 LOC  OBJ         LINE        SOURCE STATEMENT

 0007 3E58         55+               MVI    A,58H           ;SET PORT 07 FOR MUX CHANNEL
 0009 D307         56+               OUT    07H             ;OUTPUT IT
 000B 0605         57+               MVI    B,05H           ;SETTLING TIME CONSTANT
 000D CD0000   E   58+               CALL   LDLY            ;WAIT FOR RDG TO SETTLE
 0010 CD0000   E   59+               CALL   RDSENS          ;GET BCD DIGITS FROM HORIBA
 0013 CD0000   E   60+               CALL   ERTRAP          ;ELIMINATE STRAY OUT OF RNGE RDG
 0016 CD0000   E   61+               CALL   PHOFS           ;SUBTRACT OFFSET OR ----
 0019 CD0000   E   62+               CALL   UNPACK          ;UNPACK RESULT FOR DISPLAY
 001C CD0000   E   63+               CALL   OFFST           ;CHECK FOR EXCESSIVE OFFSET 50MV
 001F 3A0000   E   64+               LDA    D2              ;SECOND DIGIT HAS DECIMAL POINT
 0022 F610         65+               ORI    10H             ;0H=NO DEC. POINT--10H=DEC. POINT
 0024 320000   E   66+               STA    D2              ;SAVE DATA
 0027 CD0000   E   67+               CALL   DISPLA          ;PUT UNPACKED DIGITS IN DSP REG
 002A C30000   E   68+               JMP    BLNKAL          ;BLANK ALL DIGITS
                   69+
                   70
                   71
                   72       RCLOFS: MCM    05H,RCLO,10H,50H,0H     ;2.5 SEC,RCHL OFF,D.P.,P 07
                   73+
 002D 3E00         74+               MVI    A,0H            ;SET PORT 05 TO CONTROL RELAYS
 002F D305         75+               OUT    05H             ;SET PORT
 0031 3E50         76+               MVI    A,50H           ;SET PORT 07 FOR MUX CHANNEL
 0033 D307         77+               OUT    07H             ;OUTPUT IT
 0035 0605         78+               MVI    B,05H           ;SETTLING TIME CONSTANT
 0037 CD0000   E   79+               CALL   LDLY            ;WAIT FOR RDG TO SETTLE
 003A CD0000   E   80+               CALL   RDSENS          ;GET BCD DIGITS FROM HORIBA
 003D CD0000   E   81+               CALL   ERTRAP          ;ELIMINATE STRAY OUT OF RNGE RDG
 0040 CD0000   E   82+               CALL   RCLO            ;SUBTRACT OFFSET OR ----
 0043 CD0000   E   83+               CALL   UNPACK          ;UNPACK RESULT FOR DISPLAY
 0046 CD0000   E   84+               CALL   OFFST           ;CHECK FOR EXCESSIVE OFFSET 50MV
 0049 3A0000   E   85+               LDA    D2              ;SECOND DIGIT HAS DECIMAL POINT
 004C F610         86+               ORI    10H             ;0H=NO DEC. POINT--10H=DEC. POINT
 004E 320000   E   87+               STA    D2              ;SAVE DATA
 0051 CD0000   E   88+               CALL   DISPLA          ;PUT UNPACKED DIGITS IN DSP REG
 0054 C30000   E   89+               JMP    BLNKAL          ;BLANK ALL DIGITS
                   90+
                   91
                   92
                   93                END

ASSEMBLY COMPLETE,    NO ERRORS
```

```
C                         WQM3

C       THIS SUBROUTINE READS EACH SENSOR 8 TIMES AND STORES EACH
C       READING IN AN ARRAY CALLED STAT.  THE 8 READINGS ARE TO BE
C       USED BY SUBROUTINE ERTRAP TO ELIMINATE ANY STRAY BAD READS.

C                                   2/25/87

C                                   VERSION 1

              SUBROUTINE      RDSENS

              INTEGER*1 RC,I,J
              INTEGER*1 N1,N2,N3,N4,PARAM,SIGN
              REAL N,STAT(8)

              COMMON/NUMB/N
              COMMON/DATA/N1,N2,N3,N4,PARAM,SIGN
              COMMON/RDAT/STAT
              COMMON/RDCNT/RC,I,J



              EXTERNAL        PACK,CONVRT


              DO 100 RC=1,8

              CALL     CONVRT
              CALL     PACK
              IF(SIGN .EQ. #00H) N=N*(-1)
       100    STAT(RC)=N
       110    CONTINUE
              RETURN

              END


MODULE INFORMATION:

    CODE AREA SIZE     = 004BH     75D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 0002H      2D
    37 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT RDSENS

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
C                           WQM3

C                           2/25/87

C                       VERSION 1

C       THIS SUBROUTINE CHECKS FOR ANY STRAY BAD READS AND RETURNS
C       A SINGLE GOOD VALUE.


        SUBROUTINE ERTRAP

        INTEGER*1 RC,I,J

        REAL N,STAT(8)

        COMMON/NUMB/N
        COMMON/RDAT/STAT
        COMMON/RDCNT/RC,I,J


        DO 100 I=1,7
        DO 100 J=I+1,8
        IF(STAT(I) . LT. STAT(J)) GO TO 100
        H=STAT(I)
        STAT(I)=STAT(J)
        STAT(J)=H
   100  CONTINUE

        N=(STAT(4)+STAT(5))/2.0

        RETURN

        END


MODULE INFORMATION:

    CODE AREA SIZE     = 00B8H    184D
    VARIABLE AREA SIZE = 0004H      4D
    MAXIMUM STACK SIZE = 0004H      4D
    35 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT ERTRAP

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
C             WQM3

C       THIS SUBROUTINE TAKES 4 BCD DIGITS IN INTEGER*1 FORM
C       AND CONVERTS(PACKS) THEM INTO ONE REAL NUMBER AND
C       STORES IT IN ADDRESS N.


C                               2/25/87
C                               VERSION 1

        SUBROUTINE      PACK

        INTEGER*1 N1,N2,N3,N4,PARAM,SIGN
        REAL N

        COMMON/DATA/N1,N2,N3,N4,PARAM,SIGN
        COMMON/NUMB/N

        N=N4*1000.0+N3*100.0+N2*10.0+N1



        RETURN
        END
```

```
MODULE INFORMATION:

    CODE AREA SIZE     = 0072H    114D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 000EH     14D
    25 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT PACK

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
      C     THIS SUBROUTINE UNPACKS A REAL NUMBER INTO 5 INTEGER*1
      C     NUMBERS FOR EVENTUAL DISPLAY.

      C                     2/25/87
      C                     VERSION 1
            SUBROUTINE      UNPACK

            REAL N
            INTEGER*1 D1,D2,D3,D4,D5

            COMMON/NUMB/N
            COMMON/DDATA/D1,D2,D3,D4,D5

            D5=N/10000.0
            D4=(N-D5*10000.0)/1000.0
            D3=(N-(D5*10000.0+D4*1000.0))/100.0
            D2=(N-(D5*10000.0+D4*1000.0+D3*100.0))/10.0
            D1=(N-(D5*10000.0+D4*1000.0+D3*100.0+D2*10.0))

            RETURN

            END


MODULE INFORMATION:

    CODE AREA SIZE     = 00CFH    207D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 000EH     14D
    22 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT UNPACK

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
      C           WQM3

      C      THIS SUBROUTINE SETS THE PACKED DIGITS INTO MEMORY.  NO OFFSET
      C      ADJUSTMENT IS REQUIRED.  THE SAME ROUTINE IS USED IN THE CAL AND
      C      MEASUREMENT MODES.  THE VALUE IS RECEIVED IN DEG C.
      C      TEMPF= DEG F; TEMPC= DEG C

      C                        5/4/87

      C                        VERSION 3


  1          SUBROUTINE TEMPS


  2          REAL N,TEMPF,TEMPC

  3          COMMON/NUMB/N
  4          COMMON/TEMPV/TEMPF,TEMPC


  5          CALL    FQ0GO

  6          TEMPF=(N*1.8+320.0)/10.0
  7          TEMPC=N/10.0
  8          N=ABS(TEMPF*10.0)

  9          RETURN

 10          END


MODULE INFORMATION:

    CODE AREA SIZE     = 0055H     85D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 0002H      2D
    30 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT TEMPS

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
C                     WQM3

C       THIS SUBROUTINE CALCULATES THE OFFSET FOR PH MEASUREMENTS.
C       IT IS USED IN THE CALIBRATION MODE. THE STANDARD SOLUTION
C       HAS A PH OF 7


C                     2/25/87

        SUBROUTINE      PHOFS

        REAL N,PHO,PH

        COMMON/NUMB/N
        COMMON/PHV/PHO,PH


        N=N-70.0

        PHO=N

        IF(PHO .GT. 10.0) N=55555.0
        IF(PHO .LT. -10.0) N=55555.0


        N=ABS(N)


        RETURN
        END
```

```
MODULE INFORMATION:

   CODE AREA SIZE     = 0073H    115D
   VARIABLE AREA SIZE = 0000H      0D
   MAXIMUM STACK SIZE = 0006H      6D
   30 LINES READ

   0 PROGRAM ERROR(S) IN PROGRAM UNIT PHOFS

   0 TOTAL PROGRAM ERROR(S)
   END OF FORTRAN COMPILATION
```

```
C                    WQM3
C       THIS SUBROUTINE SUBTRACTS THE OFFSET FROM THE MEASURED PRODUCT
C       WATER. THE RESULT IS ALSO USED IN THE RESIDUAL CHLORINE
C       CORRECTION FACTOR CALCULATION.

C                    2/25/87

C                    VERSION 1

        SUBROUTINE      PHMC

        REAL N,PHO,PH

        COMMON/PHV/PHO,PH
        COMMON/NUMB/N

        N=N-PHO

        PH=N
        N=ABS(N)

        RETURN

        END
```

```
MODULE INFORMATION:

    CODE AREA SIZE      = 0024H     36D
    VARIABLE AREA SIZE  = 0000H      0D
    MAXIMUM STACK SIZE  = 0002H      2D
    27 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT PHMC

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

ASM80 :F1:TDSO.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS


```
 LOC  OBJ        LINE       SOURCE STATEMENT

                        ;                          WQM3
                        ;
                        ;
                                      NAME TDS01              ;2/18/87
                        ;
                        ;             GETS TDS OFFSET VALUE FOR EACH RANGE
                        ;
                        ;                    PORT 05
                        ;
                        ;                    7 6 5 4 3 2 1 0
                        ;                    - - - - - - - 1 TDS RANGE (1)
                        ;                    - - - - - - 1 - TDS RANGE (10)
                        ;                    - - - - - 1 - - TDS RANGE (50)
                        ;                    - - - - X - - - /TEMP,PH
                        ;                    - - - 1 - - - - LED 2 "1"
                        ;                    - - 1 - - - - - LED 1 "1"
                        ;                    - X - - - - - - /DET 1,DET 2
                        ;                    1 - - - - - - - UNUSED
                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                        ;
                        ;

                                      EXTRN RDSENS,PACK,CONDO,UNPACK,LDLY,DISPLA,BLNKAL,ERTRAP
                                      EXTRN D2,OFFST

                                      PUBLIC  TDSOF,TDSRNG

                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                                 DSEG

 0000                                 TDSRNG: DS      1        ;RANGE INDICATOR STRG


                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                             CSEG


 0000 3E04                     TDSOF: MVI     A,04H           ;SET PORT 05 FOR TDS 50 RANGE
 0002 320000    D                     STA     TDSRNG          ;RANGE INDICATOR
 0005 CD1B00    C                     CALL    TDS1            ;DO TDS OFFSET FORTRAN ROUTINE
 0008 3E02                            MVI     A,02H           ;SET PORT 05 FOR TDS 10 RANGE
 000A 320000    D                     STA     TDSRNG
 000D CD1B00    C                     CALL    TDS1
 0010 3E01                            MVI     A,01H           ;SET PORT 05 FOR TDS 1 RANGE
 0012 320000    D                     STA     TDSRNG
 0015 CD1B00    C                     CALL    TDS1
 0018 C30000    E                     JMP     BLNKAL          ;BLANK ALL DIGITS; SAVE BATTERY

                        ;             WAIT FOR NEXT DO IT (INTERRUPT) STACK RESET BY TYPBR


 001B 3EFF                     TDS1:  MVI     A,0FFH          ;BLANK DISPLAY CONTROL BITS
 001D D301                            OUT     01H             ;OUTPUT BITS - BLANK DISPLAY
```

```
 LOC  OBJ           SOURCE STATEMENT

001F 3A0000   D            LDA     TDSRNG      ;GET RANGE INDICATOR BITS AGAIN
0022 D305                  OUT     05H         ;OUTPUT  RELAY SELECT BITS
0024 060A                  MVI     B,0AH       ;10 LOOPS FOR 5 SEC SETTLE TIME
0026 CD0000   E            CALL    LDLY        ;.5 SEC DELAY LOOP
0029 3E5C                  MVI     A,5CH       ;MUX CHANNEL & ENABLE BITS
002B D307                  OUT     07H         ;SET MUX
002D CD0000   E            CALL    RDSENS      ;SAMPLE THE TDS CKT OUTPUT
0030 CD0000   E            CALL    ERTRAP      ;TEST FOR STRAY BAD READ
0033 CD0000   E            CALL    PACK        ;PACK DIGITS INTO SINGLE INTEGER
0036 CD0000   E            CALL    CONDO       ;SAVE RESULT FOR LATER CALCULATION
0039 CD0000   E            CALL    UNPACK      ;UNPACK DATA FOR DISPLAY
003C CD0000   E            CALL    OFFST       ;CHECK FOR EXCESSIVE OFFSET >50MV
003F 3A0000   E            LDA     D2          ;GET DIGIT 2 DATA FOR D.P. ADDITION
0042 F610                  ORI     10H         ;4TH BIT HIGH FOR D.P.
0044 320000   E            STA     D2          ;PUT DATA BACK WITH D.P.
0047 CD0000   E            CALL    DISPLA      ;DISPLA RESULT FOR 15 SEC.
004A C9                    RET

                           END
```

ASSEMBLY COMPLETE,   NO ERRORS

```
ASM80 :F1:TDSM.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1        TDSM1    PAGE    1


 LOC  OBJ         LINE        SOURCE STATEMENT

                        ;       WQM3

                                NAME    TDSM1           ;2/18/87


                        ;       TDS MEASUREMENT SUBROUTINE- SUBTRACTS OFFSET, COMPENSATES FOR
                        ;       TEMPERATURE, AND CHECKS RANGE.  CALLS FORTRAN ROUTINE TDS## FOR
                        ;       RANGE TEST.  IF OUT OF RANGE AUTOMATICALLY SETS NEXT LOWER RANGE.


                        ;                       PORT 05
                        ;
                        ;                       7 6 5 4 3 2 1 0
                        ;                       - - - - - - - 1 TDS RANGE (1)
                        ;                       - - - - - - 1 - TDS RANGE (10)
                        ;                       - - - - - 1 - - TDS RANGE (50)
                        ;                       - - - - X - - - /TEMP, PH
                        ;                       - - - 1 - - - - LED 2 "1"
                        ;                       - - 1 - - - - - LED 1 "1"
                        ;                       - X - - - - - - /DET 1, DET2
                        ;                       1 - - - - - - - UNUSED
                        ;
                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                EXTRN RDSENS,PACK,UNPACK,CONDC,LDLY,DISPLA,BLNKAL,ERTRAP
                                EXTRN TDS50,TDS10,TDS1
                                EXTRN D1,D2,D3,D4,D5
                                EXTRN TDSRNG
                                EXTRN EOD


                                PUBLIC TDSMB

                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;


                                                DSEG

 0000                           RANGE:  DS      1

                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                                CSEG

 0000 3E04                      TDSMB:  MVI     A,04H           ;SET PORT 05 FOR TDS 50 RANGE
 0002 320000    E                       STA     TDSRNG          ;TDS50 RANGE INDICATOR
 0005 D305                              OUT     05H             ;OUTPUT TO PORT;
 0007 CD4700    C                       CALL    TDSMC           ;GET READING
 000A CD0000    E                       CALL    TDS50           ;CHECK IN RANGE 5000-50000 MG/L
 000D 3A0000    D                       LDA     RANGE           ;GET RANGE STATUS CODE
 0010 FE55                              CPI     55H             ;IN RANGE?
 0012 CA5A00    C                       JZ      TDSMD           ;YES, DISPLAY RESULT

 0015 3E02                              MVI     A,02H           ;SET PORT FOR TDS10 500-5000 MG/L
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

 0017 320000   E     55              STA     TDSRNG
 001A D305           56              OUT     05H
 001C CD4700   C     57              CALL    TDSMC
 001F CD0000   E     58              CALL    TDS10         ;CHECK IN RANGE 500-5000 MG/L
 0022 3A0000   D     59              LDA     RANGE
 0025 FE55           60              CPI     55H
 0027 CA5A00   C     61              JZ      TDSMD
                     62
 002A 3E01           63              MVI     A,01H         ;SET PORT 05 FOR TDS1 0-500 MG/L
 002C 320000   E     64              STA     TDSRNG
 002F D305           65              OUT     05H
 0031 CD4700   C     66              CALL    TDSMC
 0034 CD0000   E     67              CALL    TDS1          ;CHECK IN RANGE 0-500 MG/L
 0037 3A0000   D     68              LDA     RANGE
 003A FE55           69              CPI     55H
 003C CA5A00   C     70              JZ      TDSMD
 003F 060E           71              MVI     B,0EH         ;OUT OF RANGE (0 DISPLAY EEEEE
 0041 CD0000   E     72              CALL    EOD           ;DISPLAY E'S
 0044 C30000   E     73              JMP     BLNKAL
                     74
 0047 060A           75      TDSMC:  MVI     B,0AH         ;5 SEC DELAY CONSTANT
 0049 CD0000   E     76              CALL    LDLY          ;WAIT 5 SEC FOR THINGS TO SETTLE
 004C 3E5C           77              MVI     A,5CH         ;MUX CHANNEL & ENABLE BITS
 004E D307           78              OUT     07H           ;SET MUX
 0050 CD0000   E     79              CALL    RDSENS        ;READ CONDUCTIVITY SENSOR, PACK DIGITS
 0053 CD0000   E     80              CALL    ERTRAP        ;CHECK FOR STRAY BAD READ
 0056 CD0000   E     81              CALL    CONDC         ;SUBTRACT OFFSET AND CALCULATE
                     82                                    ;FOR TEMPERATURE COMPENSATION.
 0059 C9             83              RET
                     84
 005A CD0000   E     85      TDSMD:  CALL    UNPACK        ;UNPACK RESULT INTO INDIVIDUAL DIGITS
 005D CD0000   E     86              CALL    DISPLA        ;DISPLAY RESULT
 0060 C30000   E     87              JMP     BLNKAL        ;BLANK ALL DIGITS; SAVE BATTERY
                     88
                     89              END

ASSEMBLY COMPLETE,    NO ERRORS
```

```
C                    WQM3

C       THIS SUBROUTINE HANDLES THE CONDUCTIVITY OFFSET FACTOR.
C       THE STANDARD SOLUTION HAS 0 CONUCTIVITY. CONDUCTIVITY IS
C       USED AS A MEASUREMENT OF TOTAL DISOLVED SOLIDS (TDS).


C                    2/25/87
C                    VERSION 1


        SUBROUTINE      CONDO

        INTEGER*1 N1,N2,N3,N4,PARAM,SIGN
        INTEGER*1 TDSRNG
        REAL N,CON05,CONOT,CON01,UC

        COMMON/DATA/N1,N2,N3,N4,PARAM,SIGN
        COMMON/NUMB/N
        COMMON/TDS/CON05,CONOT,CON01,UC
        COMMON/TDSR/TDSRNG

        CALL    FQ060

        IF(TDSRNG .EQ. #04H) GO TO 10
        IF(TDSRNG .EQ. #02H) GO TO 20
        IF(TDSRNG .EQ. #01H) GO TO 30


   10   CON05=N
        N=ABS(N)
        RETURN

   20   CONOT=N
        N=ABS(N)
        RETURN

   30   CON01=N
        N=ABS(N)
        RETURN

        END


MODULE INFORMATION:

    CODE AREA SIZE     = 0063H     99D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 0002H      2D
    43 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT CONDO

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
C       THIS SUBROUTINE TESTS FOR IN RANGE TDS READING ON 5000-50000 MG/L
C       RANGE. THE ROUTINE RETURNS TO THE CALLING PROGRAM,TDSM, A HEX
C       55 IF THE READING IS IN RANGE; OTHERWISE IT RETURNS A HEX AA.

C                               3/16/87

C                               VERSION 2

        SUBROUTINE      TDS50

        INTEGER*1 RANGE
        REAL N

        COMMON/NUMB/N
        COMMON/RNGE/RANGE

        IF(N .GE. 6000.0) GO TO 10
        RANGE=#0AAH
        RETURN

   10   RANGE=#55H
        RETURN

        END


MODULE INFORMATION:

    CODE AREA SIZE     = 0022H     34D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 0002H      2D
    26 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT TDS50

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
C                               WQM3

C       THIS SUBROUTINE TESTS FOR IN RANGE TDS READING ON 500-5000 MG/L
C       RANGE. THE ROUTINE RETURNS TO THE CALLING PROGRAM,TDSM, A HEX
C       55 IF THE READING IS IN RANGE; OTHERWISE IT RETURNS A HEX AA.

C                               3/16/87

C                               VERSION 2

              SUBROUTINE     TDS10

              INTEGER*1 RANGE
              REAL N

              COMMON/NUMB/N
              COMMON/RNGE/RANGE

              IF(N .GE. 600.0) GO TO 10
              RANGE=#0AAH
              RETURN

       10     RANGE=#55H
              RETURN

              END
```

```
MODULE INFORMATION:

    CODE AREA SIZE     = 0022H     34D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 0002H      2D
    26 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT TDS10

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
C                              WQM3

C      THIS SUBROUTINE TESTS FOR IN RANGE TDS READING ON 0-500 MG/L
C      RANGE. THE ROUTINE RETURNS TO THE CALLING PROGRAM,TDSM, A HEX
C      55 IF THE READING IS IN RANGE; OTHERWISE IT RETURNS A HEX AA.

C                              2/26/87

C                              VERSION 1

       SUBROUTINE    TDS1

       INTEGER*1 RANGE
       REAL N

       COMMON/NUMB/N
       COMMON/RNGE/RANGE

       IF(N .LT. 0.0) GO TO 10
       RANGE=#55H
       RETURN

   10  RANGE=#0AAH
       RETURN

       END
```

MODULE INFORMATION:

```
CODE AREA SIZE     = 0022H    34D
VARIABLE AREA SIZE = 0000H     0D
MAXIMUM STACK SIZE = 0002H     2D
26 LINES READ

0 PROGRAM ERROR(S) IN PROGRAM UNIT TDS1

0 TOTAL PROGRAM ERROR(S)
END OF FORTRAN COMPILATION
```

```
      C                  WQM3

      C        THIS SUBROUTINE SUBTRACTS THE OFFSET AND CALCULATES THE
      C        TOTAL DISOLVED SOLIDS AS A FUNCTION OF TEMPERATURE.

      C                  4/8/87

      C                  VERSION 3

               SUBROUTINE     CONDC

               REAL    TEMPF,Y,Q
               REAL N,CON05,CON0T,CON01,UC

               INTEGER*1 N1,N2,N3,N4,PARAM,SIGN
               INTEGER*1 TDSRNG

               COMMON/DATA/N1,N2,N3,N4,PARAM,SIGN
               COMMON/NUMB/N
               COMMON/TEMPV/TEMPF,TEMPC

               COMMON/TDS/CON05,CON0T,CON01,UC
               COMMON/TDSR/TDSRNG


      C             CHECK CONDUCTIVITY RANGE

               CALL    FQ0GO

               IF(TDSRNG .EQ. #01H) GO TO 10
               IF(TDSRNG .EQ. #02H) GO TO 100
               IF(TDSRNG .EQ. #04H) GO TO 500

      C             SUBTRACT OFFSET AND PUT IN REAL FORM

         10    UC=(N-CON01)/1000.0
               GO TO 1000

        100    UC=(N-CON0T)/100.0
               GO TO 1000

        500    UC=(N-CON05)/10.0

               IF(UC .GE. 88.0) GOTO 800
               GO TO 1000

        800    Q=.00387*TEMPF+.702

               UC=UC*Q

       1000    N=17754.8/TEMPF**.8354*UC**(1.00398*TEMPF**.01195)

      C        FURTHER CORRECTIONS IN BECKMAN CURVES FOR TEMPERATURE

               IF((TEMPF .LE. 30.0) .OR. (TEMPF .LT. 56.0)) GO TO 2010

               IF((TEMPF .LE. 56.0) .OR. (TEMPF .LT. 64.0)) GO TO 2030
```

```
      GO TO 2040

 2010 Y=.00346*(TEMPF-30.0)+.972
      GO TO 3000

 2030 Y=1.062
      GO TO 3000

 2040 Y=.00172*(64.0-TEMPF)+1.062

C     CORRECTED TDS IN MG/LITER

 3000 N=N*Y
      N=ABS(N)

      RETURN

      END
```

```
MODULE INFORMATION:

    CODE AREA SIZE     = 01EDH    493D
    VARIABLE AREA SIZE = 0008H      8D
    MAXIMUM STACK SIZE = 000CH     12D
    76 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT CONDC

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

ASM80 :F1:TURCAL.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS

ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1   TURBO2   PAGE   1

```
 LOC  OBJ         LINE        SOURCE STATEMENT

                        ;                   WQM3


                                NAME    TURBO2          ;3/9/87


                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                        ;DESCRIPTION:  SUBROUTINE TO CONTROL THE TURBIDITY SENSOR ELEMENTS
                        ;              AND TO INVOKE OTHER SUBROUTINES TO CALCULATE THE
                        ;              TURBIDITY VALUE.  THE OFFSET VALUE IS STORED FOR
                        ;              LATER USE BY THE TURBIDITY CALCULATION ROUTINE.
                        ;
                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                        EXTRN   TBCTRL,TURBO,UNPACK,OFFST,DISPLA,BLNKAL
                                        EXTRN   D2,TURLN,TEMPTO,RDSENS,ERTRAP,LDLY

                                        PUBLIC  TURBOF

                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                                CSEG

 0000 CD0000    E               TURBOF: CALL    TBCTRL          ;READ TURBIDITY HEAD AND STORE DATA
 0003 3E54                              MVI     A,54H           ;GET TEMPERATURE  PORT 7 MUX CHANNEL
 0005 D307                              OUT     07H             ;       SET PORT
 0007 0605                              MVI     B,05H           ;       SETTLING TIME CONSTANT
 0009 CD0000    E                       CALL    LDLY            ;       WAIT FOR RDG TO SETTLE
 000C CD0000    E                       CALL    RDSENS          ;       DO A/D READ TEMP
 000F CD0000    E                       CALL    ERTRAP          ;       ELIMINATE BAD READ
 0012 CD0000    E                       CALL    TEMPTO          ;       CONVERT TEMP AND STORE
 0015 CD0000    E                       CALL    TURLN           ;CALCULATE LN()
 0018 CD0000    E                       CALL    TURBO           ;ROUTINE TO PROCESSED DATA OFFSET
 001B CD0000    E                       CALL    UNPACK          ;UNPACK DIGITS FOR DISPLAY
 001E CD0000    E                       CALL    OFFST           ;CHECK FOR EXCESSIVE OFFSET
 0021 3A0000    E                       LDA     D2              ;SECOND DIGIT DECIMAL POINT
 0024 F610                              ORI     10H             ;0H NO DEC PT.  10H DEC PT.
 0026 320000    E                       STA     D2              ;STORE IT HERE
 0029 CD0000    E                       CALL    DISPLA          ;PUT UNPACKED DIGITS IN DISP REG
 002C C30000    E                       JMP     BLNKAL          ;BLANK ALL DIGITS

                                        END
```

ASSEMBLY COMPLETE,   NO ERRORS

```
C              WQM3

C       THIS SUBROUTINE SETS THE PACKED DIGITS INTO MEMORY.  NO OFFSET
C       ADJUSTMENT IS REQUIRED.  THE SAME ROUTINE IS USED IN THE CAL AND
C       MEASUREMENT MODES.  THE VALUE IS RECEIVED IN DEG C.
C       TEMPF= DEG F; TEMPC= DEG C

C                                5/4/87

C                                VERSION 3

        SUBROUTINE TEMPTO

        REAL N,TTEMPO

        COMMON/NUMB/N
        COMMON/TURSOL/UCTUR,TTEMPO,TTEMPM

        CALL    FQ06D

        TTEMPO=(N*1.8+320.0)/10.0

        RETURN

        END
```

```
MODULE INFORMATION:

     CODE AREA SIZE     = 002EH     46D
     VARIABLE AREA SIZE = 0000H      0D
     MAXIMUM STACK SIZE = 0002H      2D
     27 LINES READ

     0 PROGRAM ERROR(S) IN PROGRAM UNIT TEMPTO

     0 TOTAL PROGRAM ERROR(S)
     END OF FORTRAN COMPILATION
```

```
C                       WQM3

C       CALCULATES FOUR BEAM MEASUREMENTS AFTER SUBTRACTING DARK
C       CURRENT AND AMPLIFIER OFFSET COMPONENTS.  THE RESULT IS
C       A NATURAL LOG

C                       3/9/87

C                       VERSION 1

        SUBROUTINE      TURLN

        REAL    N,UCTUR
        REAL    DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

        COMMON/NUMB/N
        COMMON/TURDTA/DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF
        COMMON/TURSOL/UCTUR,TTEMPO,TTEMPM
        CALL    F00GO

        UCTUR=ALOG(((E1D1-DKD1)/(E1D2-DKD2))*((E2D2-DKD2)/(E2D1-DKD1)))

        RETURN

        END
```

```
MODULE INFORMATION:

   CODE AREA SIZE     = 0074H    116D
   VARIABLE AREA SIZE = 0008H      8D
   MAXIMUM STACK SIZE = 000EH     14D
   25 LINES READ

   0 PROGRAM ERROR(S) IN PROGRAM UNIT TURLN

   0 TOTAL PROGRAM ERROR(S)
   END OF FORTRAN COMPILATION
```

```
ASM80 :F1:TBCTL.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1        TCTRL4   PAGE    1


  LOC  OBJ         LINE        SOURCE STATEMENT

                      1 ;                    WQM3
                      2
                      3               NAME TCTRL4             ;4/7/87
                      4
                      5 ;        THIS SUBROUTINE CONTROLS THE TURBIDITY HEAD.  IT READS
                      6 ;        AND STORES THE HEAD DATA AND THE K FACTOR.
                      7
                      8
                      9 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                     10
                     11          EXTRN   LDLY,TURDK1,TURDK2,TE1D1,TE1D2,TE2D1,TE2D2,TKF
                     12          EXTRN   DATDSP,DBLANK
                     13
                     14          PUBLIC  TBCTRL
                     15
                     16 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                     17
                     18                       CSEG
                     19
  0000 FB            20          TBCTRL: EI                   ;ENABLE INTERRUPT
  0001 3EBF          21                  MVI     A,0BFH       ;D2-D5 BLANK
  0003 320000   E    22                  STA     DBLANK       ;BLANK DATA STRG
  0006 3E6C          23                  MVI     A,6CH        ;TURB MUX2 CH4
  0008 D307          24                  OUT     07H          ;SET MUX
  000A 3E80          25                  MVI     A,80H        ;D1 DARK
  000C D305          26                  OUT     05H          ;SET HEAD
  000E 0604          27                  MVI     B,04H        ;2 SEC DELAY
  0010 CD0000   E    28                  CALL    LDLY         ;WAIT FOR CKT SETTLE
  0013 CD0000   E    29                  CALL    TURDK1       ;READ D1 DARK VALUE
  0016 3E0A          30                  MVI     A,0AH
  0018 CD0000   E    31                  CALL    DATDSP
                     32
  001B 3EC0          33                  MVI     A,0C0H       ;D2 DARK
  001D D305          34                  OUT     05H          ;SET HEAD
  001F 0604          35                  MVI     B,04H        ;2 SEC DELAY
  0021 CD0000   E    36                  CALL    LDLY         ;WAIT FOR CKTS TO STABALIZE
  0024 CD0000   E    37                  CALL    TURDK2       ;READ D2 DARK VALUE
  0027 3E0B          38                  MVI     A,0BH
  0029 CD0000   E    39                  CALL    DATDSP
                     40
  002C 3EA0          41                  MVI     A,0A0H       ;E1D1
  002E D305          42                  OUT     05H          ;SET HEAD
  0030 0604          43                  MVI     B,04H        ;DELAY FACTOR
  0032 CD0000   E    44                  CALL    LDLY         ;SETTLE TIME
  0035 CD0000   E    45                  CALL    TE1D1        ;READ LED1 WITH DIODE 1
  0038 3E0C          46                  MVI     A,0CH
  003A CD0000   E    47                  CALL    DATDSP
                     48
  003D 3E90          49                  MVI     A,90H        ;E2D1
  003F D305          50                  OUT     05H          ;
  0041 0604          51                  MVI     B,04H        ;
  0043 CD0000   E    52                  CALL    LDLY         ;SETTLE TIME
  0046 CD0000   E    53                  CALL    TE2D1        ;READ LED 2 WITH DIODE 1
  0049 3E0D          54                  MVI     A,0DH
```

```
 LOC  OBJ         LINE        SOURCE STATEMENT

 004B CD0000   E                      CALL    DATDSP
 004E 3EE0                            MVI     A,0E0H         ;E1D2
 0050 D305                            OUT     05H            ;
 0052 0604                            MVI     B,04H          ;
 0054 CD0000   E                      CALL    LDLY           ;
 0057 CD0000   E                      CALL    TE1D2          ;READ LED 1 WITH DIODE 2
 005A 3E0E                            MVI     A,0EH
 005C CD0000   E                      CALL    DATDSP
 005F 3ED0                            MVI     A,0D0H         ;E2D2
 0061 D305                            OUT     05H            ;
 0063 0604                            MVI     B,04H          ;
 0065 CD0000   E                      CALL    LDLY           ;
 0068 CD0000   E                      CALL    TE2D2          ;READ LED 2 WITH DIODE 2
 006B 3E0F                            MVI     A,0FH
 006D CD0000   E                      CALL    DATDSP
 0070 3E68                            MVI     A,68H          ;K FACTOR MUX 2, CHANNEL 3
 0072 D307                            OUT     07H            ;SET MUX
 0074 0604                            MVI     B,04H          ;LET MUX SETTLE
 0076 CD0000   E                      CALL    LDLY           ;
 0079 CD0000   E                      CALL    TKF            ;READ K FACTOR ANALOG FROM CKT BOARD
 007C C9                              RET
                                      END

ASSEMBLY COMPLETE,    NO ERRORS
```

ASM80 :F1:TURMES.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS

ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1   TURBM2   PAGE   1

```
 LOC  OBJ           LINE        SOURCE STATEMENT

                         ;              WQM3


                                NAME    TURBM2          ;3/9/87


                         ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                         ;DESCRIPTION:  SUBROUTINE TO CONTROL THE TURBIDITY SENSOR ELEMENTS
                         ;              AND TO INVOKE OTHER SUBROUTINES TO CALCULATE THE
                         ;              TURBIDITY VALUE.  THE OFFSET VALUE IS STORED FOR
                         ;              LATER USE BY THE TURBIDITY CALCULATION ROUTINE.
                         ;
                         ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                        EXTRN   TBCTRL,TURBC,UNPACK,OFFST,DISPLA,BLNKAL
                                        EXTRN   D2,TURLN,TEMPTM,RDSENS,ERTRAP,LDLY

                                        PUBLIC  TURBM

                         ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                                CSEG

 0000 CD0000    E               TURBM:  CALL    TBCTRL          ;GET TEMPERATURE  HEAD AND STORE DATA
 0003 3E54                              MVI     A,54H           ;       PORT 7 MUX CHANNEL
 0005 D307                              OUT     07H             ;       SET PORT
 0007 0605                              MVI     B,05H           ;       SETTLING TIME CONSTANT
 0009 CD0000    E                       CALL    LDLY            ;       WAIT FOR RDG TO SETTLE
 000C CD0000    E                       CALL    RDSENS          ;       DO A/D READ TEMP
 000F CD0000    E                       CALL    ERTRAP          ;       ELIMINATE BAD READ
 0012 CD0000    E                       CALL    TEMPTM          ;       CONVERT TEMP AND STORE
 0015 CD0000    E                       CALL    TURLN           ;CALCULATE LN[]
 0018 CD0000    E                       CALL    TURBC           ;CALCULATE NTU
 001B CD0000    E                       CALL    UNPACK          ;UNPACK DIGITS FOR DISPLAY
 001E 3A0000    E                       LDA     D2              ;SECOND DIGIT DECIMAL POINT
 0021 E6EF                              ANI     0EFH            ;0H NO DEC PT.   10H DEC PT.
 0023 320000    E                       STA     D2              ;STORE IT HERE
 0026 CD0000    E                       CALL    DISPLA          ;PUT UNPACKED DIGITS IN DISP REG
 0029 C30000    E                       JMP     BLNKAL          ;BLANK ALL DIGITS

                                        END
```

ASSEMBLY COMPLETE,   NO ERRORS

```
C                  WQM3

C                  3/3/87

C           VERSION 1

C           THIS SUBROUTINE READS AND CHECKS TURBIDITY DATA FROM
C           THE TURB. HEAD.  DATA IS THEN SAVED FOR LATER CALCULATION
C           OF TURBIDITY.

      SUBROUTINE      TURDK1

      REAL N
      REAL DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

      COMMON/NUMB/N
      COMMON/TURDTA/DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

      EXTERNAL RDSENS,ERTRAP


      CALL    RDSENS
      CALL    ERTRAP
      DKD1=N

      RETURN

      END
```

```
MODULE INFORMATION:

    CODE AREA SIZE     = 0010H     16D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 0002H      2D
    28 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT TURDK1

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
C                       WQM3

C                       3/3/87

C                 VERSION 1

C                 THIS SUBROUTINE READS AND CHECKS TURBIDITY DATA FROM
C                 THE TURB. HEAD.  DATA IS THEN SAVED FOR LATER CALCULATION
C                 OF TURBIDITY.

            SUBROUTINE      TURDK2

            REAL N
            REAL DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF


            COMMON/NUMB/N
            COMMON/TURDTA/DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

            EXTERNAL RDSENS,ERTRAP

            CALL    RDSENS
            CALL    ERTRAP
            DKD2=N

            RETURN

            END
```

MODULE INFORMATION:

```
    CODE AREA SIZE     = 0010H     16D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 0002H      2D
    28 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT TURDK2

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
      C                   WQM3

      C                   3/3/87

      C              VERSION 1

      C              THIS SUBROUTINE READS AND CHECKS TURBIDITY DATA FROM
      C              THE TURB. HEAD.  DATA IS THEN SAVED FOR LATER CALCULATION
      C              OF TURBIDITY.

              SUBROUTINE     TE1D1

              REAL N
              REAL DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

              COMMON/NUMB/N
              COMMON/TURDTA/DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

              EXTERNAL RDSENS,ERTRAP

              CALL    RDSENS
              CALL    ERTRAP
              E1D1=N

              RETURN

              END
```

```
MODULE INFORMATION:

   CODE AREA SIZE     = 0010H    16D
   VARIABLE AREA SIZE = 0000H     0D
   MAXIMUM STACK SIZE = 0002H     2D
   27 LINES READ

   0 PROGRAM ERROR(S) IN PROGRAM UNIT TE1D1

   0 TOTAL PROGRAM ERROR(S)
   END OF FORTRAN COMPILATION
```

```
C                          WQM3

C                          3/3/87

C                     VERSION 1

C                     THIS SUBROUTINE READS AND CHECKS TURBIDITY DATA FROM
C                     THE TURB. HEAD.  DATA IS THEN SAVED FOR LATER CALCULATION
C                     OF TURBIDITY.

            SUBROUTINE      TE2D1

            REAL N
            REAL DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

            COMMON/NUMB/N
            COMMON/TURDTA/DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

            EXTERNAL RDSENS,ERTRAP

            CALL    RDSENS
            CALL    ERTRAP
            E2D1=N

            RETURN

            END


MODULE INFORMATION:

    CODE AREA SIZE     = 0010H     16D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 0002H      2D
    27 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT TE2D1

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
C                    WQM3

C                    3/3/87

C              VERSION 1

C              THIS SUBROUTINE READS AND CHECKS TURBIDITY DATA FROM
C              THE TURB. HEAD.  DATA IS THEN SAVED FOR LATER CALCULATION
C              OF TURBIDITY.

      SUBROUTINE     TE1D2

      REAL N
      REAL DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

      COMMON/NUMB/N
      COMMON/TURDTA/DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

      EXTERNAL RDSENS,ERTRAP

      CALL    RDSENS
      CALL    ERTRAP
      E1D2=N

      RETURN

      END


MODULE INFORMATION:

   CODE AREA SIZE     = 0010H     16D
   VARIABLE AREA SIZE = 0000H      0D
   MAXIMUM STACK SIZE = 0002H      2D
   27 LINES READ

   0 PROGRAM ERROR(S) IN PROGRAM UNIT TE1D2

   0 TOTAL PROGRAM ERROR(S)
   END OF FORTRAN COMPILATION
```

```
      C                   WQM3

      C                   3/3/87

      C             VERSION 1

      C             THIS SUBROUTINE READS AND CHECKS TURBIDITY DATA FROM
      C             THE TURB. HEAD.  DATA IS THEN SAVED FOR LATER CALCULATION
      C             OF TURBIDITY.

            SUBROUTINE     TE2D2

            REAL N
            REAL DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

            COMMON/NUMB/N
            COMMON/TURDTA/DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

            EXTERNAL RDSENS,ERTRAP

            CALL    RDSENS
            CALL    ERTRAP
            E2D2=N

            RETURN

            END
```

```
MODULE INFORMATION:

   CODE AREA SIZE      = 0010H     16D
   VARIABLE AREA SIZE = 0000H      0D
   MAXIMUM STACK SIZE = 0002H      2D
   27 LINES READ

   0 PROGRAM ERROR(S) IN PROGRAM UNIT TE2D2

   0 TOTAL PROGRAM ERROR(S)
   END OF FORTRAN COMPILATION
```

```
C                         WQM3

C                         3/3/87

C                  VERSION 1

C                  THIS SUBROUTINE READS AND CHECKS K FACTOR DATA
C                  DATA IS THEN SAVED FOR LATER TURBIDITY CALCULATION
C

            SUBROUTINE      TKF

            REAL N
            REAL DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

            COMMON/NUMB/N
            COMMON/TURDTA/DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

            EXTERNAL RDSENS,ERTRAP

            CALL    RDSENS
            CALL    ERTRAP
            KF=N

            RETURN

            END
```

```
MODULE INFORMATION:

     CODE AREA SIZE     = 0010H     16D
     VARIABLE AREA SIZE = 0000H      0D
     MAXIMUM STACK SIZE = 0002H      2D
     27 LINES READ

     0 PROGRAM ERROR(S) IN PROGRAM UNIT TKF

     0 TOTAL PROGRAM ERROR(S)
     END OF FORTRAN COMPILATION
```

```
      C           WQM3
      C     THIS SUBROUTINE CALCULATES THE OFFSET FOR TURBIDITY
      C     MEASUREMENTS. IT IS USED IN THE CALIBRATE MODE.
      C     THE STANDARD SOLUTION HAS ZERO TURBIDITY.


      C                 3/3/87

      C                 VERSION 1

            SUBROUTINE    TURBO

            INTEGER*1 D1,D2,D3,D4,D5

            REAL N,TURBF,TURB,UCTUR
            REAL DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

            COMMON/TURDTA/DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF
            COMMON/DDATA/D1,D2,D3,D4,D5
            COMMON/NUMB/N
            COMMON/TUR/TURBF,TURB
            COMMON/TURSOL/UCTUR,TTEMPO,TTEMPM

            CALL    F0060

            TURBF=UCTUR


            IF(TURBF .LT. 5.0) GO TO 100
            IF(TURBF .GT. 8.0) GO TO 100
            N=0

            GO TO 1000

      C     MAKE D5,D4 GREATER THAN ZERO TO FORCE UNACCEPTABLE OFFSET DISPLAY (F'S)

        100 N=55555.0

       1000 RETURN


            END
```

MODULE INFORMATION:

```
    CODE AREA SIZE     = 0054H     84D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 0002H      2D
    43 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT TURBO

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
C                       WQM3

C       THIS SUBROUTINE SUBTRACTS THE OFFSET FROM THE TURBIDITY
C       MEASUREMENT. THE TEST SOLUTION TURBIDITY IS ZERO.

C                       3/23/87
C                       VERSION 3

        SUBROUTINE      TURBC

        REAL N,TURBF,TURB,UCTUR,TTEMPO,TTEMPM,NTU
        REAL DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

        COMMON/TUR/TURBF,TURB
        COMMON/NUMB/N
        COMMON/TURSOL/UCTUR,TTEMPO,TTEMPM
        COMMON/TURDTA/DKD1,DKD2,E1D1,E1D2,E2D1,E2D2,KF

        CALL    FQ0GO

C       CALCULATE NTU VALUE - CORRECTED FOR TEMPERATURE

        KF=KF/100000.0


        TURB=(UCTUR-(TURBF-(.00175*(TTEMPO-TTEMPM))))/KF


C       SET N EQUAL TO NTU VALUE FOR DISPLAY

        N=ABS(TURB)

        RETURN
        END
```

```
MODULE INFORMATION:

   CODE AREA SIZE     = 0054H     84D
   VARIABLE AREA SIZE = 0004H      4D
   MAXIMUM STACK SIZE = 0002H      2D
   37 LINES READ

   0 PROGRAM ERROR(S) IN PROGRAM UNIT TURBC

   0 TOTAL PROGRAM ERROR(S)
   END OF FORTRAN COMPILATION
```

```
      C            WQM3

      C       THIS SUBROUTINE SETS THE PACKED DIGITS INTO MEMORY.  NO OFFSET
      C       ADJUSTMENT IS REQUIRED.  THE SAME ROUTINE IS USED IN THE CAL AND
      C       MEASUREMENT MODES.  THE VALUE IS RECEIVED IN DEG C.
      C       TEMPF= DEG F; TEMPC= DEG C

      C                              5/4/87

      C                              VERSION 3

  1           SUBROUTINE TEMPTM

  2           REAL N,TTEMPM

  3           COMMON/NUMB/N
  4           COMMON/TURSOL/UCTUR,TTEMPO,TTEMPM

  5           CALL    FQ060

  6           TTEMPM=(N*1.8+320.0)/10.0

  7           RETURN

  8           END
```

MODULE INFORMATION:

```
    CODE AREA SIZE     = 002EH     46D
    VARIABLE AREA SIZE = 0000H      0D
    MAXIMUM STACK SIZE = 0002H      2D
    27 LINES READ

    0 PROGRAM ERROR(S) IN PROGRAM UNIT TEMPTM

    0 TOTAL PROGRAM ERROR(S)
    END OF FORTRAN COMPILATION
```

```
C               WQM3
C       THIS SUBROUTINE SUBTRACTS THE OFFSET. IT ALSO CHECKS FOR FURTHER
C       NEEDED CORRECTION. IF THE PH IS EQUAL TO OR GREATER THAN FIVE
C       IT MUST BE CORRECTED.

C                       4/9/87
C
C                       VERSION 2


        SUBROUTINE      RCLMC


        INTEGER*1 N1,N2,N3,N4,PARAM,SIGN

        REAL N,PHO,PH,RCLOF,RCLU,FICF,TEMPC,P,TC,KT

        COMMON/DATA/N1,N2,N3,N4,PARAM,SIGN
        COMMON/NUMB/N
        COMMON/PHV/PHO,PH
        COMMON/RCL/RCLOF,RCLU,FICF,P,TC
        COMMON/TEMPV/TEMPF,TEMPC
        COMMON/RCVA/A1,A2,A3,A4,A5

C       SUBTRACT OFFSET



        CALL    FQ0GO

        RCLU=N-RCLOF

C       PH ( 5?

        IF(PH .LT. 50.0) GO TO 200
        GO TO 1000


  200   N=ABS(RCLU)

        RETURN

 1000   P=PH/10.0

        KT=(.05623*TEMPC+1.486)
        FICF=100*(1/(1+(KT*10**P*1E-8)))

C               CALCULATE RESID. CHLORINE

        N=ABS(ANINT(100.0/FICF*RCLU))

        RETURN

        END
```

```
      C                        WQM3

      C     THIS SUBROUTINE GETS THE RESIDUAL CHLORINE OFFSET FACTOR.
      C     THE SAMPLE SOLUTION PH IS LESS THAN 6.0. THE SOLUTION
      C     IS DE-MINERALIZED WATER.

      C                        2/25/87

      C                        VERSION 1

            SUBROUTINE         RCLO


            INTEGER*1 N1,N2,N3,N4,PARAM,SIGN
            REAL N,RCLOF,RCLU,FICF,P,TC

            COMMON/DATA/N1,N2,N3,N4,PARAM,SIGN
            COMMON/NUMB/N
            COMMON/RCL/RCLOF,RCLU,FICF,P,TC


            RCLOF=N

            N=ABS(N)


            RETURN

            END
```

```
MODULE INFORMATION:

   CODE AREA SIZE     = 0015H     21D
   VARIABLE AREA SIZE = 0000H      0D
   MAXIMUM STACK SIZE = 0002H      2D
   30 LINES READ

   0 PROGRAM ERROR(S) IN PROGRAM UNIT RCLO

   0 TOTAL PROGRAM ERROR(S)
   END OF FORTRAN COMPILATION
```

```
ASM80 :F1:ATOD.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1        ADC1     PAGE    1


  LOC  OBJ         LINE        SOURCE STATEMENT

                      ;              WQM3
                      ;
                      ;
                                     NAME    ADC1            ;2/16/87
                      ;
                      ;
                      ;              ANALOG TO DIGITAL DATA CONVERSION SUBROUTINE
                      ;
                      ;
                      ;
                      ;                      PORT 07
                      ;                      7 6 5 4 3 2 1 0
                      ;                      - - - - - - X X A/D DIGIT 0 SELECT
                      ;                      - - - - - - X Y A/D DIGIT 1 SELECT
                      ;                      - - - - - X - - MUX A0 (CHANNEL ADDR)
                      ;                      - - - - X - - - MUX A1 (CHANNEL ADDR)
                      ;                      - - - 1 - - - - TEMP, PH, TDS, R.CHLR MUX ENABLE "1"
                      ;                      - - 1 - - - - - TURB MUX ENABLE "1"
                      ;                      - X - - - - - - UNUSED
                      ;                      1 - - - - - - - START CONVERSION
                      ;                      PORT 06
                      ;
                      ;                      7 6 5 4 3 2 1 0
                      ;                      - - - - - - - X BCD DATA IN 1
                      ;                      - - - - - - X - BCD DATA IN 2
                      ;                      - - - - - X - - BCD DATA IN 4
                      ;                      - - - - X - - - BCD DATA IN 8
                      ;                      - - - X - - - - UNUSED
                      ;                      - - 1 - - - - - CONVERSION COMPLETE "1"
                      ;                      - 1 - - - - - - OVERFLOW "1"
                      ;                      X - - - - - - - SIGN  1=+  0=-
                      ;
                      ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                                     EXTRN   EOD,BLNKAL
                                     PUBLIC  CONVRT,N1,N2,N3,N4
                      ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                                             DSEG
  0000                               TRYCTR: DS      1              ;READ OVFL COUNTER
  0001                               N1:     DS      1              ;LSD --->
  0002                               N2:     DS      1              ;-+-
  0003                               N3:     DS      1              ;-+--
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0004                55              N4:     DS      1            ;*---  N4 N3 N2 N1
0005                56              PARAM:  DS      1            ;NOT USED
0006                57              SIGN:   DS      1            ;RDG POLARITY (SIGN) STRG
                    58
                    59
                    60 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                    61
                    62                      CSEG
                    63
                    64
0000 3E00           65        CONVRT: MVI     A,0H         ;INITIALIZE OVERFLOW COUNTER
0002 320000    D    66                STA     TRYCTR       ;SAVE IT HERE
                    67
0005 DB07           68        ATD:    IN      07H          ;GET PORT 7 BITS FOR SOC
0007 F680           69                ORI     80H          ;RAISE BIT 7 (SOC)
0009 D307           70                OUT     07H          ;OUT TO PORT 7 ADC
000B 00             71                NOP                  ;DELAY A LITTLE
000C DB07           72                IN      07H          ;GET  PORT TO LOWER SOC LINE
000E E6FC           73                ANI     0FCH         ;LOWER BIT 7
0010 D307           74                OUT     07H          ;LOWER SOC LINE
                    75
0012 DB06           76        CONVDN: IN      06H          ;CHECK FOR END OF CONVERSION
0014 E620           77                ANI     20H          ;END OF CONVERSION BIT ONLY
0016 FE20           78                CPI     20H          ;DONE?
0018 C21200    C    79                JNZ     CONVDN       ;NO,TRY AGAIN
001B DB06           80                IN      06H          ;YES, GET OVERFLOW BIT
001D E640           81                ANI     40H          ;OVFLW ONLY
001F FE40           82                CPI     40H          ;OVERFLOW ="1"?
0021 CA5D00    C    83                JZ      OVFL         ;YES, GO HANDLE SITUATION
                    84
0024 DB07           85        DIG1:   IN      07H          ;GET PORT TO SET A/D DIGIT ADDR
0026 E6FC           86                ANI     0FCH         ;BITS 0,1="0" DIGIT 1 LSD
0028 D307           87                OUT     07H          ;SET ADDR
002A DB06           88                IN      06H          ;GET DATA BYTE
002C E680           89        POLAR:  ANI     80H          ;SIGN BIT ONLY
002E 320600    D    90                STA     SIGN         ;SAVE IT HERE
0031 DB06           91                IN      06H          ;GET BYTE AGAIN FOR DATA
0033 E60F           92                ANI     0FH          ;BCD DATA ONLY
0035 320100    D    93                STA     N1           ;SAVE LSD HERE
                    94
0038 DB07           95        DIG2:   IN      07H          ;BITS TO SET ADDR FOR LSD+1
003A 3C             96                INR     A            ;ADD 1 TO BYTE TO INCREMENT ADDR
003B D307           97                OUT     07H          ;SET A/D 2ND DIGIT ADDR
003D DB06           98                IN      06H          ;GET SECOND DIG BCD VALUE
003F E60F           99                ANI     0FH          ;BCD DATA ONLY
0041 320200    D   100                STA     N2           ;SAVE 2ND DIGIT VALUE HERE
                   101
0044 DB07          102        DIG3:   IN      07H
0046 3C            103                INR     A
0047 D307          104                OUT     07H
0049 DB06          105                IN      06H
004B E60F          106                ANI     0FH
004D 320300    D   107                STA     N3
                   108
0050 DB07          109        DIG4:   IN      07H
```

```
  LOC  OBJ          LINE        SOURCE STATEMENT

  0052 3C            110               INR     A
  0053 D307          111               OUT     07H
  0055 DB06          112               IN      06H
  0057 E60F          113               ANI     0FH
  0059 320400   D    114               STA     N4
  005C C9            115               RET                    ;GO BACK AFTER A/D CONVERSION
                     116
                     117
  005D 3A0000   D    118       OVFL:   LDA     TRYCTR         ;GET NUMBER OF TRYS TO READ
  0060 3C            119               INR     A              ;INCREMENT VALUE
  0061 320000   D    120               STA     TRYCTR         ;SAVE NEW VALUE
  0064 FE03          121               CPI     03H            ;4TH READ?
  0066 CA6C00   C    122               JZ      ERROR          ;YES, DISPLAY ERROR
  0069 C30500   C    123               JMP     ATD            ;NOT 4TH TRY; TRY AGAIN
                     124
  006C 060E          125       ERROR:  MVI     B,0EH          ;DISPLAY EEEEE
  006E CD0000   E    126               CALL    EOD            ;DISPLAY THEM
  0071 C30000   E    127               JMP     BLNKAL
                     128
                     129               END

ASSEMBLY COMPLETE,    NO ERRORS
```

```
ASM80 :F1:DISPLY.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1        DISPLY   PAGE    1


 LOC  OBJ        LINE       SOURCE STATEMENT

                        ;                   WQM3
                        ;
                        ;                    PORT 01
                        ;
                        ;                   7 6 5 4 3 2 1 0
                        ;                   - - - - - - - 1 UNUSED
                        ;                   - - - - - - X - /WE
                        ;                   - - - - - 1 - - 5TH DIGIT BLANK
                        ;                   - - - - 1 - - - 4TH DIGIT BLANK
                        ;                   - - - 1 - - - - 3RD DIGIT BLANK
                        ;                   - - 1 - - - - - 2ND DIGIT BLANK
                        ;                   - 1 - - - - - - 1ST DIGIT BLANK
                        ;                   1 - - - - - - - UNUSED

                        ;                   PORT 00
                        ;
                        ;                   7 6 5 4 3 2 1 0
                        ;                   - - - - - - - X LSB BCD DATA
                        ;                   - - - - - - X - BCD DATA
                        ;                   - - - - - X - - BCD DATA
                        ;                   - - - - X - - - MSB BCD DATA (DIGIT)
                        ;                   - - - X - - - - DECIMAL POINT
                        ;                   - - X - - - - - A1 DIGIT ADDRESS MM74C917
                        ;                   - X - - - - - - A2 DIGIT ADDRESS
                        ;                   X - - - - - - - A3 DIGIT ADDRESS


                                    NAME DISPLY2          ;4/7/87


                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                    EXTRN   LDLY,D1,D2,D3,D4,D5

                                    PUBLIC  DISPLA,DSPLY,BLNKAL,DATDSP,DBLANK


                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                            DSEG

0000                           DBLANK: DS   1


                        ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                            CSEG

```

```
 LOC  OBJ            LINE        SOURCE STATEMENT

 0000 3E83             55         DISPLA: MVI     A,83H       ;SETUP FOR DIGIT BLANKING
 0002 320000      D    56                 STA     DBLANK
                       57
                       58
 0005 3A0000      E    59         DBLNK5: LDA     D5          ;GET 5TH DIGIT
 0008 FE00             60                 CPI     0H          ;= ZERO?
 000A C24500      C    61                 JNZ     DSPLY       ;NO, DISPLAY ALL DIGITS
 000D 3A0000      D    62                 LDA     DBLANK      ;YES,GET DIGIT BLANK INFO
 0010 F687             63                 ORI     87H         ;5TH DIGIT BLANK ADDED
 0012 320000      D    64                 STA     DBLANK      ;SAVE IT
                       65
 0015 3A0000      E    66         DBLNK4: LDA     D4          ;GET 4TH DIGIT VALUE
 0018 FE00             67                 CPI     0H
 001A C24500      C    68                 JNZ     DSPLY
 001D 3A0000      D    69                 LDA     DBLANK
 0020 F688             70                 ORI     88H         ;BLANK 4TH DIGIT =0
 0022 320000      D    71                 STA     DBLANK
                       72
 0025 3A0000      E    73         DBLNK3: LDA     D3          ;GET 3RD DIGIT VALUE
 0028 FE00             74                 CPI     0H
 002A C24500      C    75                 JNZ     DSPLY
 002D 3A0000      D    76                 LDA     DBLANK
 0030 F690             77                 ORI     90H
 0032 320000      D    78                 STA     DBLANK
                       79
 0035 3A0000      E    80         DBLNK2: LDA     D2
 0038 FE00             81                 CPI     0H
 003A C24500      C    82                 JNZ     DSPLY
 003D 3A0000      D    83                 LDA     DBLANK
 0040 F6A0             84                 ORI     0A0H
 0042 320000      D    85                 STA     DBLANK
                       86
                       87
                       88
 0045 3A0000      E    89         DSPLY:  LDA     D5          ;DISPLAY DATA
 0048 E61F             90                 ANI     1FH         ;ZERO ADDRESS AREA
 004A F680             91                 ORI     80H         ;INCLUDE DIGIT ADDRESS BITS
 004C CD7A00      C    92                 CALL    DATDSP      ;LIGHT THE LAMPS
                       93
 004F 3A0000      E    94         DSPLY4: LDA     D4
 0052 E61F             95                 ANI     1FH
 0054 F660             96                 ORI     60H
 0056 CD7A00      C    97                 CALL    DATDSP
                       98
 0059 3A0000      E    99         DSPLY3: LDA     D3
 005C E61F            100                 ANI     1FH
 005E F640            101                 ORI     40H
 0060 CD7A00      C   102                 CALL    DATDSP
                      103
 0063 3A0000      E   104         DSPLY2: LDA     D2
 0066 E61F            105                 ANI     1FH
 0068 F620            106                 ORI     20H
 006A CD7A00      C   107                 CALL    DATDSP
                      108
 006D 3A0000      E   109         DSPLY1: LDA     D1
```

```
LOC  OBJ           SOURCE STATEMENT

0070 E61F                     ANI     1FH
0072 F600                     ORI     00H
0074 CD7A00   C               CALL    DATDSP
0077 CD8800   C               CALL    DSPTMR          ;DISPLAY FOR 15 SECONDS
                                                      ;THEN BLANK ALL DIGITS


007A D300             DATDSP: OUT     00H             ;LOAD MM74C917 REGISTERS
007C 3A0000   D               LDA     DBLANK          ;LEADING 0 BLANK INFO
007F E6FD                     ANI     0FDH            ;LOWER WE/ LINE MM74C917 WRT EN.
0081 D301                     OUT     01H             ;OUTPUT BLNKG & WRT ENABLE
0083 F602                     ORI     02H             ;RAISE WE/ LINE
0085 D301                     OUT     01H             ;OUTPUT IT
0087 C9                       RET                     ;GO BACK


0088 FB               DSPTMR: EI                      ;RE-ENABLE INTERRUPTS
0089 DB02                     IN      02H             ;GET MEAS TYPE BITS
008B E63F                     ANI     3FH             ;CAL MEAS TYPE BITS
008D FE1D                     CPI     1DH             ;TDS OFFSET ?
008F CA9800   C               JZ      SHORTD          ;YES, 5 SEC DISPLAY
0092 0618                     MVI     B,18H           ;24 LOOPS
0094 CD0000   E               CALL    LDLY            ;.5 SEC DELAY LOOP
0097 C9                       RET
0098 0608             SHORTD: MVI     B,08H           ;5 SEC DISPLAY LOOP CONSTANT
009A CD0000   E               CALL    LDLY            ;DELAY
009D C9                       RET



009E 3EFF             BLNKAL: MVI     A,0FFH          ;CONTROL TO BLANK ALL DIGITS
00A0 D301                     OUT     01H
00A2 C39E00   C               JMP     BLNKAL          ;WAIT HERE FOR NEXT DO IT


                 ;                          BLANK 5TH DIGIT          DBLANK=87H
                 ;                                5TH,4TH DIGITS          =8FH
                 ;                                5TH,4TH,3RD DIGITS      =9FH
                 ;                                5TH,4TH,3RD,2ND DIGITS  =BFH


                              END

ASSEMBLY COMPLETE,   NO ERRORS
```

ASM80 :F1:OFTST.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOL

ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1   OFTST1   PAGE   1

```
  LOC  OBJ         LINE        SOURCE STATEMENT

                         ;              WQM3
                                 NAME   OFTST1                 ;2/17/87
                         ;              SUBROUTINE CHECKS FOR OFFSET MEASUREMENTS GREATER THAN
                         ;              50 MILLIVOLTS. IF > 50MV FFFFF IS DISPLAYED BUT ERROR
                         ;              IS NOT FATAL. VALUE CAN BE USED FOR MEASUREMENT CYCLE.
                         ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                                        EXTRN   D5,D4,D3,D2,D1
                                        EXTRN   EOD
                                        PUBLIC  OFFST
                         ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                                                  CSEG
  0000 3A0000    E               OFFST: LDA     D5             ;GET 5TH DIGIT
  0003 FE00                             CPI     0H             ;= 0 ?
  0005 C22A00    C                      JNZ     HI             ;NO > 0 OFFSET HIGH
  0008 3A0000    E                      LDA     D4             ;YES GET 4TH DIGIT
  000B FE00                             CPI     0H             ;= 0 ?
  000D C22A00    C                      JNZ     HI
  0010 3A0000    E                      LDA     D3
  0013 FE00                             CPI     0H
  0015 C22A00    C                      JNZ     HI
  0018 3A0000    E                      LDA     D2
  001B 07                               RLC
  001C 07                               RLC
  001D 07                               RLC
  001E 07                               RLC
  001F 47                               MOV     B,A
  0020 3A0000    E                      LDA     D1
  0023 B0                               ORA     B
  0024 FE50                             CPI     50H
  0026 D22A00    C                      JNC     HI             ;YES
  0029 C9                               RET                    ;NO
  002A 060F                      HI:    MVI     B,0FH
  002C CD0000    E                      CALL    EOD
  002F C9                               RET
                                        END
```

ASSEMBLY COMPLETE,   NO ERRORS

```
ASM80 :F1:EROVF.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1        EROVF    PAGE    1


 LOC  OBJ         LINE       SOURCE STATEMENT

                          ;
                          ;                       WOM3


                                NAME EROVF                     ;2/17/87


                          ;     SUBROUTINE USED TO DISPLAY ERROR MESSAGES
                          ;             E=ERRORS
                          ;             F=OFFSET MEASUREMENTS TOO LARGE - NOT FATAL
                          ;             8=INITIAL DISPLAY SEGMENT CHECK

                          ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                        EXTRN   DISPLA,BLNKAL
                                        EXTRN   D1,D2,D3,D4,D5

                                        PUBLIC  EOD

                          ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;


                                                        CSEG

 0000 78                        EOD:    MOV     A,B
 0001 320000      E                     STA     D1
 0004 320000      E                     STA     D2
 0007 320000      E                     STA     D3
 000A 320000      E                     STA     D4
 000D 320000      E                     STA     D5
 0010 CD0000      E                     CALL    DISPLA
 0013 C9                                RET
                                        END

ASSEMBLY COMPLETE,    NO ERRORS
```

```
ASM80 :F1:TRNSFR.SRC XREF DEBUG MACROFILE MOD85 NOSYMBOLS


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.1        TRNSFR   PAGE    1


  LOC  OBJ         LINE        SOURCE STATEMENT

                          ;               WQM3

                          ;               TRANSFERS DATA FROM ARRAY TO A VARIABLE


                                          NAME     TRNSFR1

                          ;               DATE:    2/17/87

                          ;        ITPTR OR IARY ADDR. IN DE
                          ;        ITEMP OR ICF ADDR. IN BC
                          ;
                          ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                          PUBLIC   TFR

                          ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

                                                   CSEG
                                                   .
  0000 1A                          TFR:   LDAX     D              ;GET LOW ADDR NIBBLE
  0001 6F                                 MOV      L,A            ;STORE IN L
  0002 13                                 INX      D              ;BUMP FOR HIGH NIBBLE ADDR.
  0003 1A                                 LDAX     D              ;GET HIGH NIBBLE ADDR
  0004 67                                 MOV      H,A            ;PUT IT IN H
  0005 7E                                 MOV      A,M            ;GET DATA FROM ARRAY
  0006 02                                 STAX     B              ;STORE IT IN ITEMP OR ICF
  0007 03                                 INX      B              ;BUMP FOR HIGH ADDR NIBBLE
  0008 AF                                 XRA      A              ;ZERO A
  0009 02                                 STAX     B              ;ZERO HIGH NIBBLE
                                                                  ;HIGHEST A0H--INT*2 POSITIVE
  000A C9                                 RET                     ;GO BACK


                                          END

ASSEMBLY COMPLETE,    NO ERRORS
```